Cross Sections measurement of ^{16}O+C from 2019 GSI data taking and Trigger studies

Angelica De Gregorio, Marco Toppi

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Steps for cross sections measurement

^{16}O beam @ 400 MeV/nucleon on a 5 mm Carbon TG

$$\sigma(Z) = \int_{E_{min}}^{E_{max}} \int_0^{\Delta\theta} \left(\frac{\partial^2\sigma}{\partial\theta\partial E_{kin}}\right) d\theta dE_{kin} = \frac{N_{frag}(Z)}{N_{prim} \cdot N_{TG} \cdot \epsilon(Z)}$$

Run	Type	Target	Events
2210	calibration	no	20463
2211	calibration	no	62782
2212	calibration	no	116349
2242	calibration	no	202728
2239	physics	C	20821
2240	physics	C	20004
2241	physics	C	20041
2251	physics	C	6863

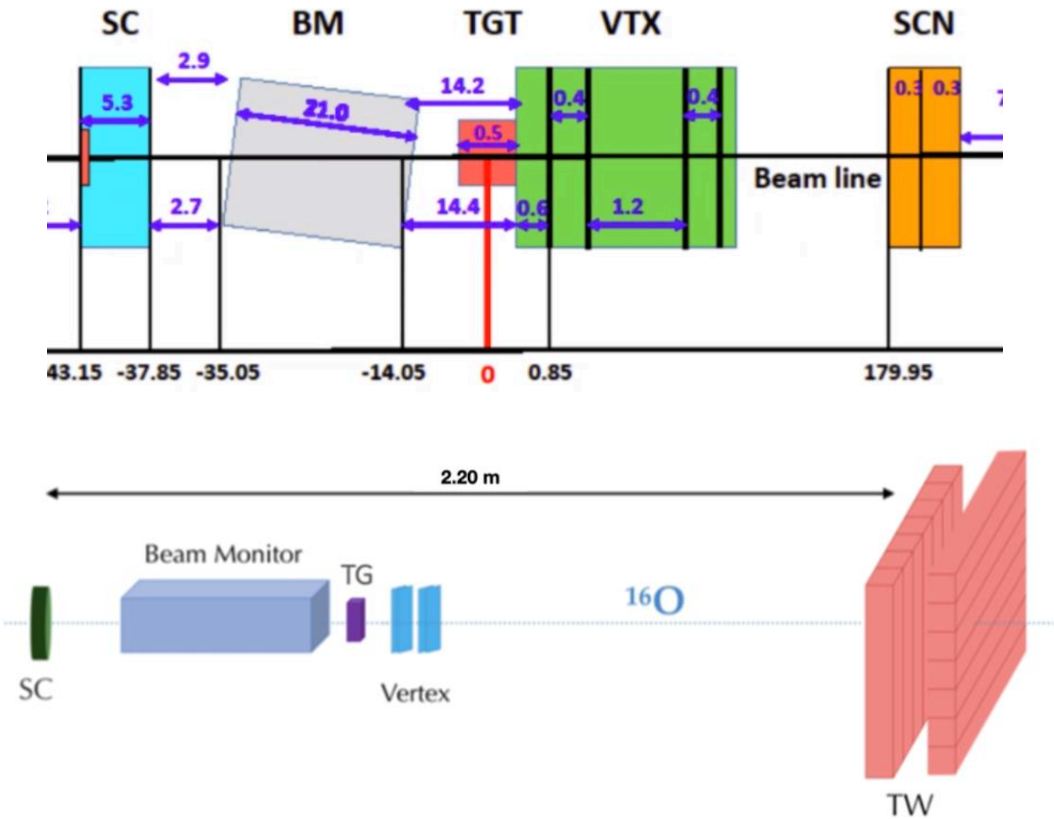
- Align FOOT detector at GSI and select angular acceptance for cross section integration (thanks Yun)
- Extract the fragments yields from ZID and TW clustering algorithms
- Compute MC efficiencies for each fragment
- Estimate fragmentation out of target for background subtraction
- Systematics study

Very low statistics and no detectors for mass identification

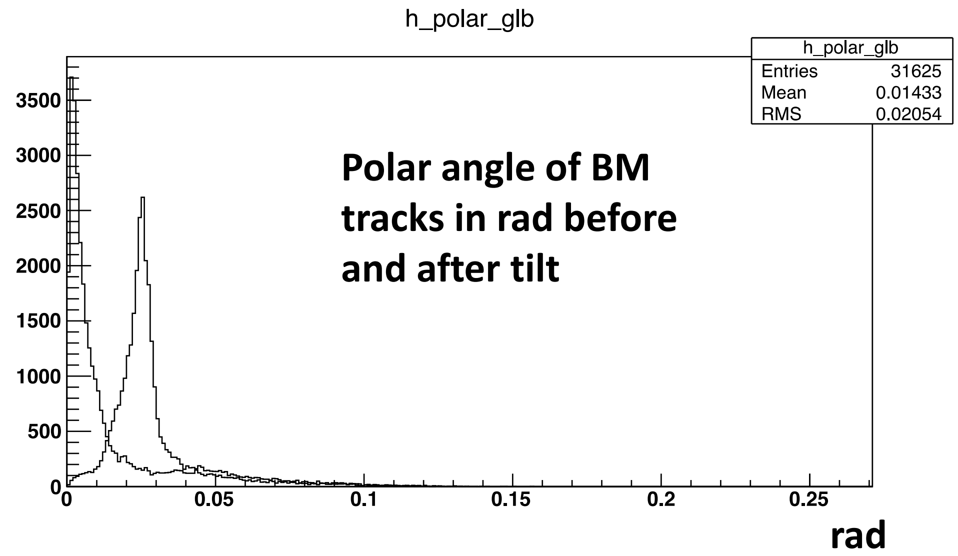
↓

cross section integrated in angular and kinetic energy interval is feasible

Beam and Beam Monitor at GSI



GSI setup (BM/TW) has needed to be aligned for Physics runs (2239,40,41,51) using run 2242 -> straight oxygen ions without TG

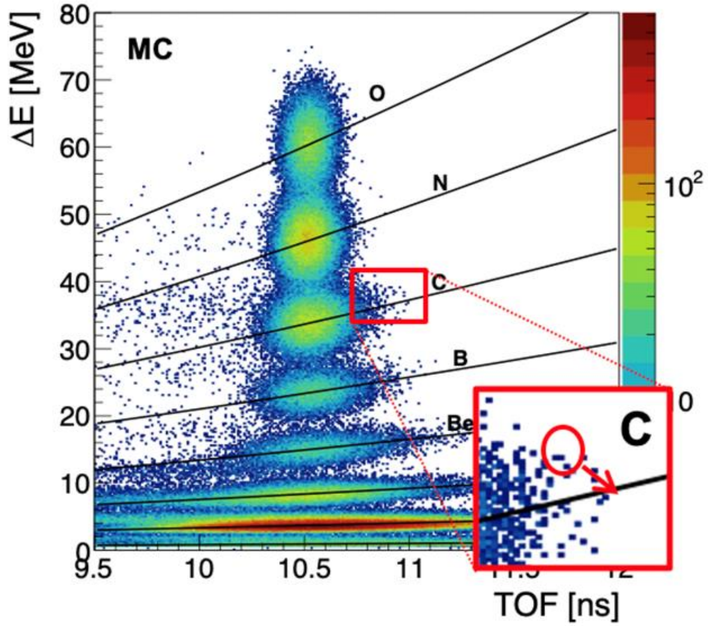


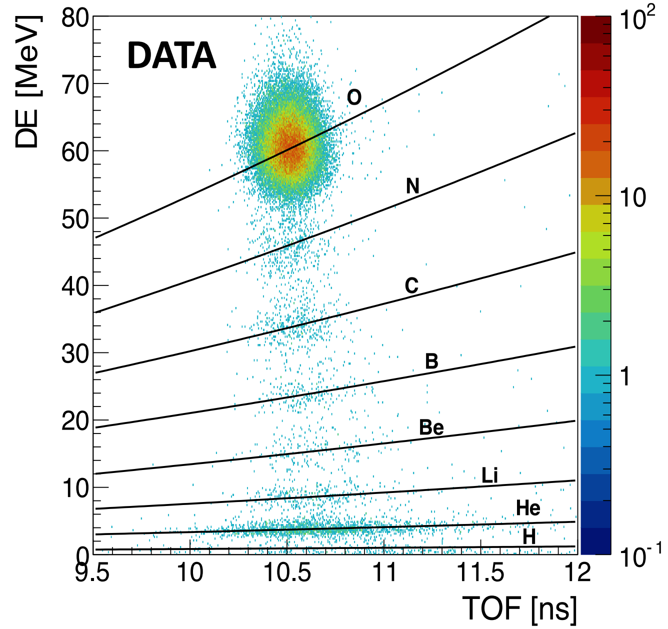
Angular resolution from TW bars crossing < 1.2mrad (0.6°)

Charge identification (ZID) algorithm

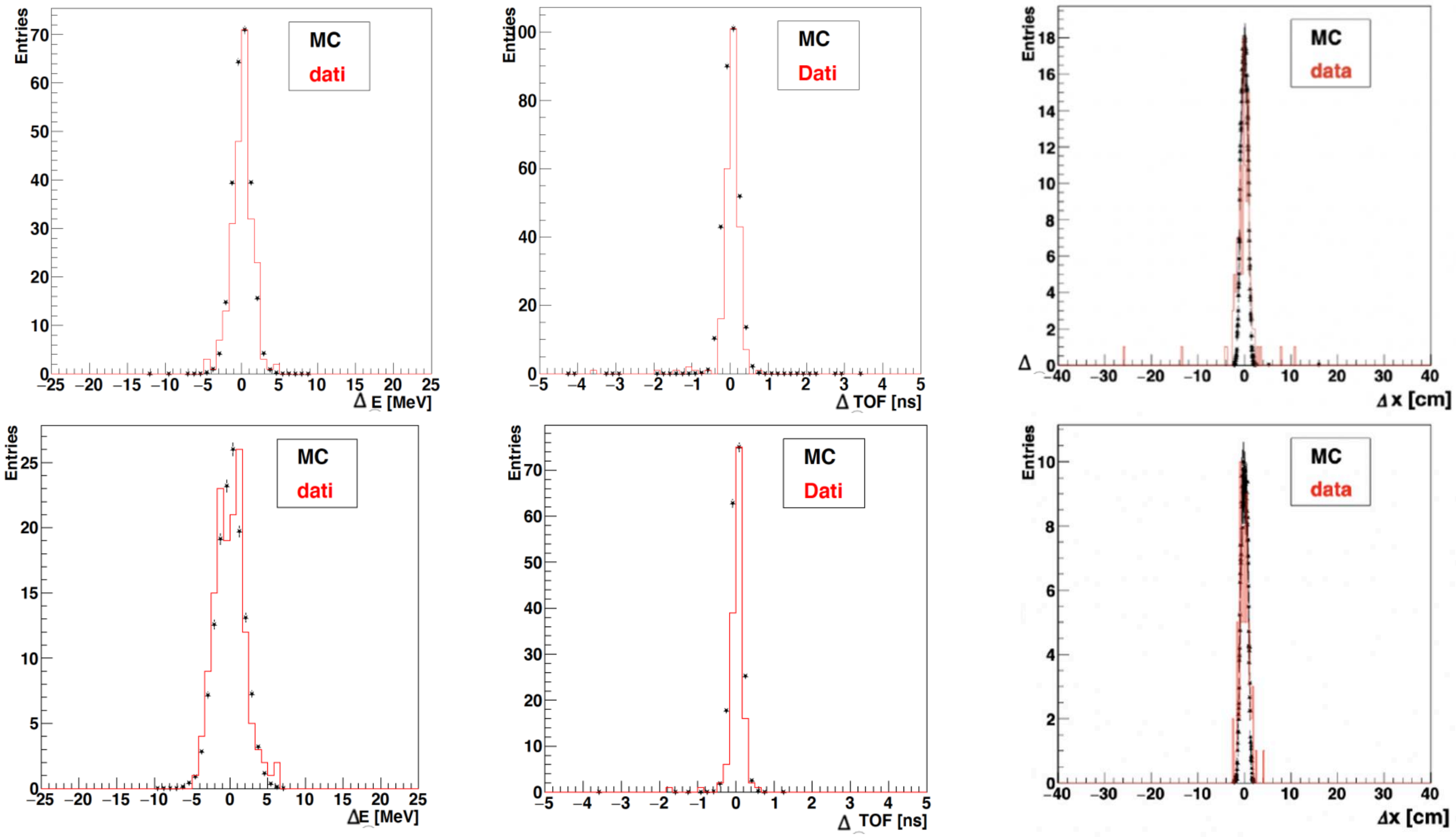
For each TW hit (Eloss, ToF) the ZID algorithm assigns a fragment charge Z

- For each region (and so for each charge) the distribution was fitted with Bethe-Bloch formula.
- Plotting the TW hits on an ΔE vs TOF plain, we can **assign** to each one the Z corresponding to the **closest Bethe-Bloch** curve.



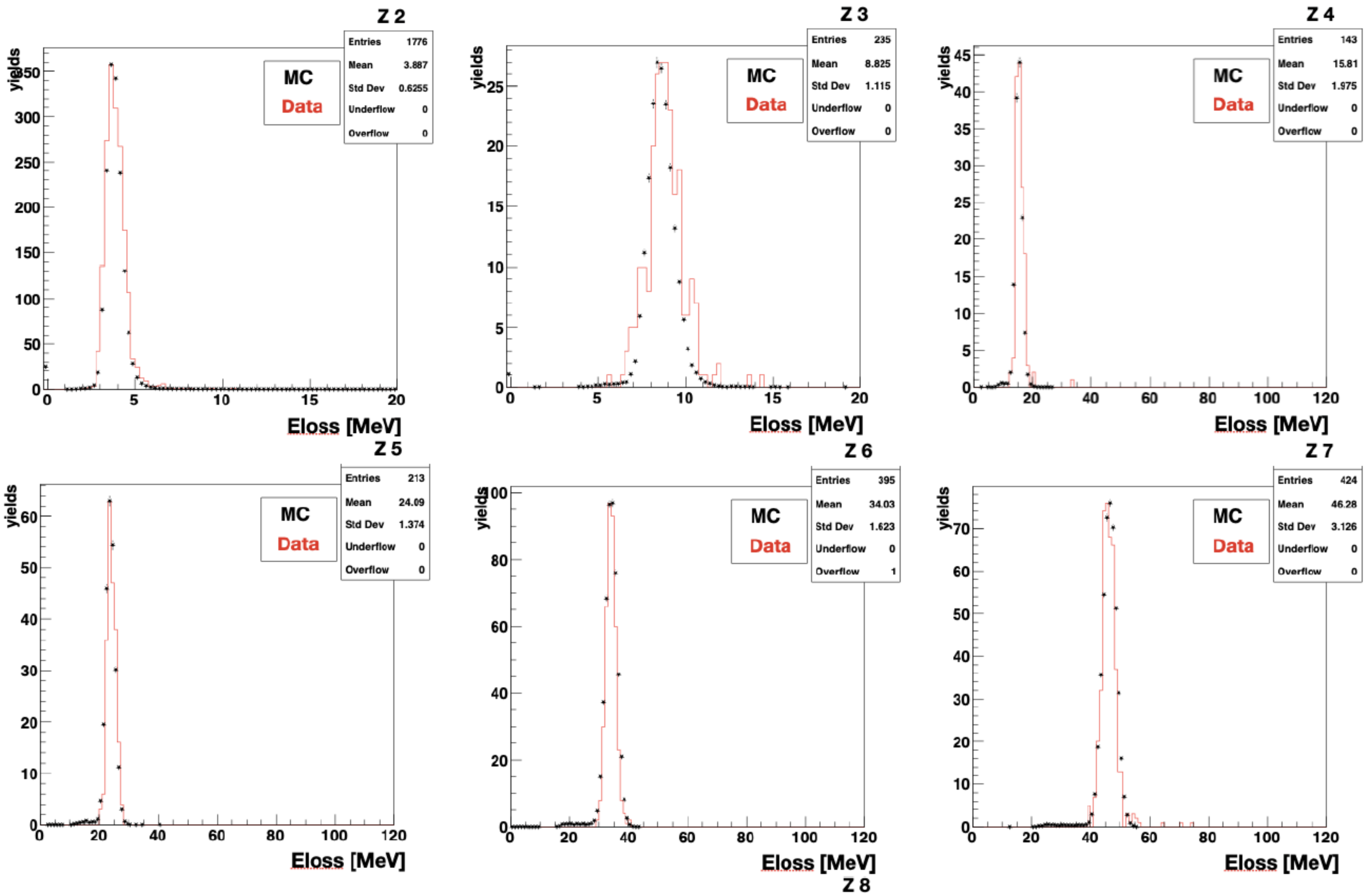


TW clustering algorithm



- Clustering algorithm associates hit bars in front and rear layer to reconstruct fragments impinging on TW
- Checking TW ZID+clustering algorithm comparing Eloss and Tof of hits matched to the cluster

Fragments identification with TW



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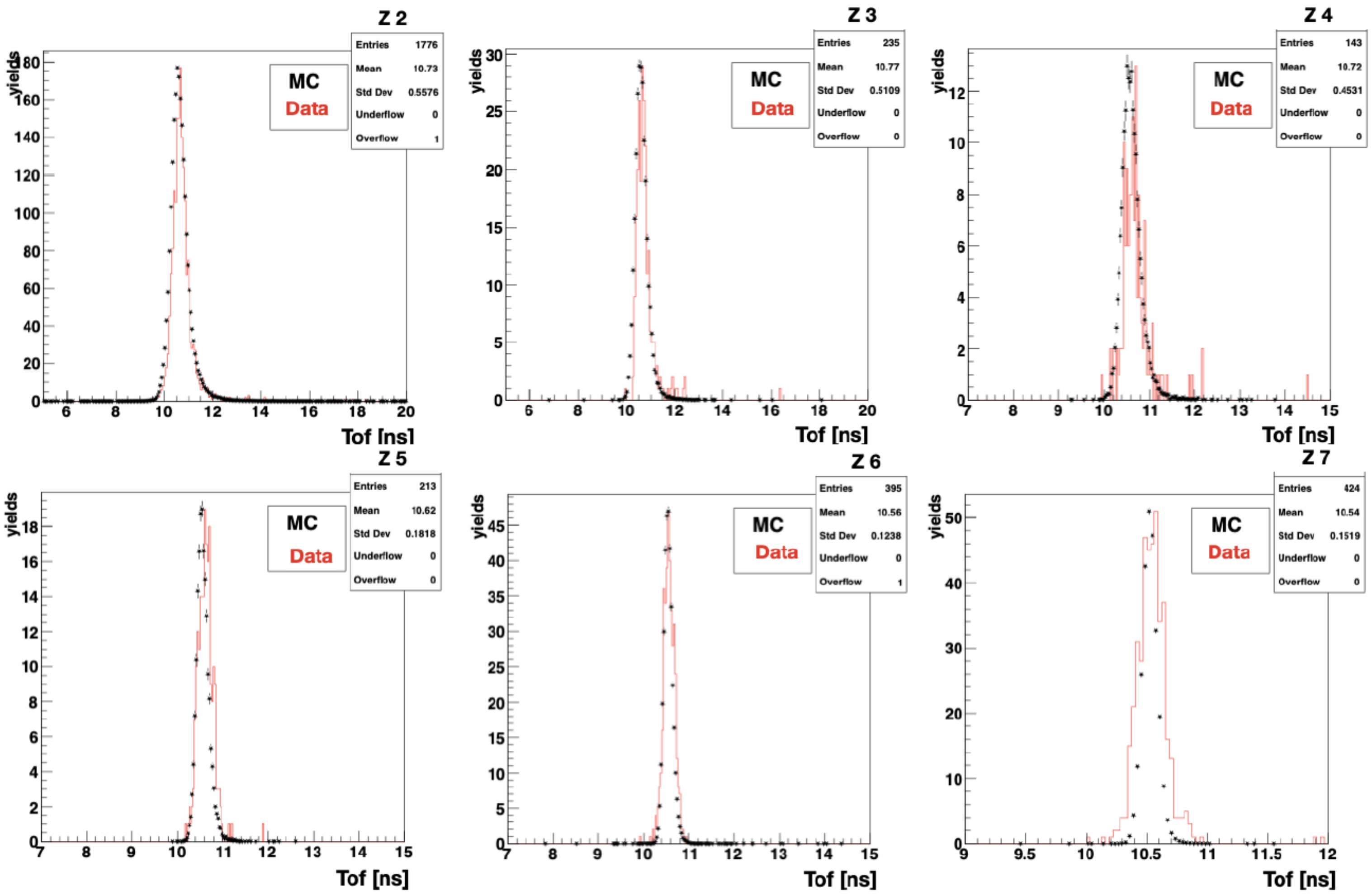
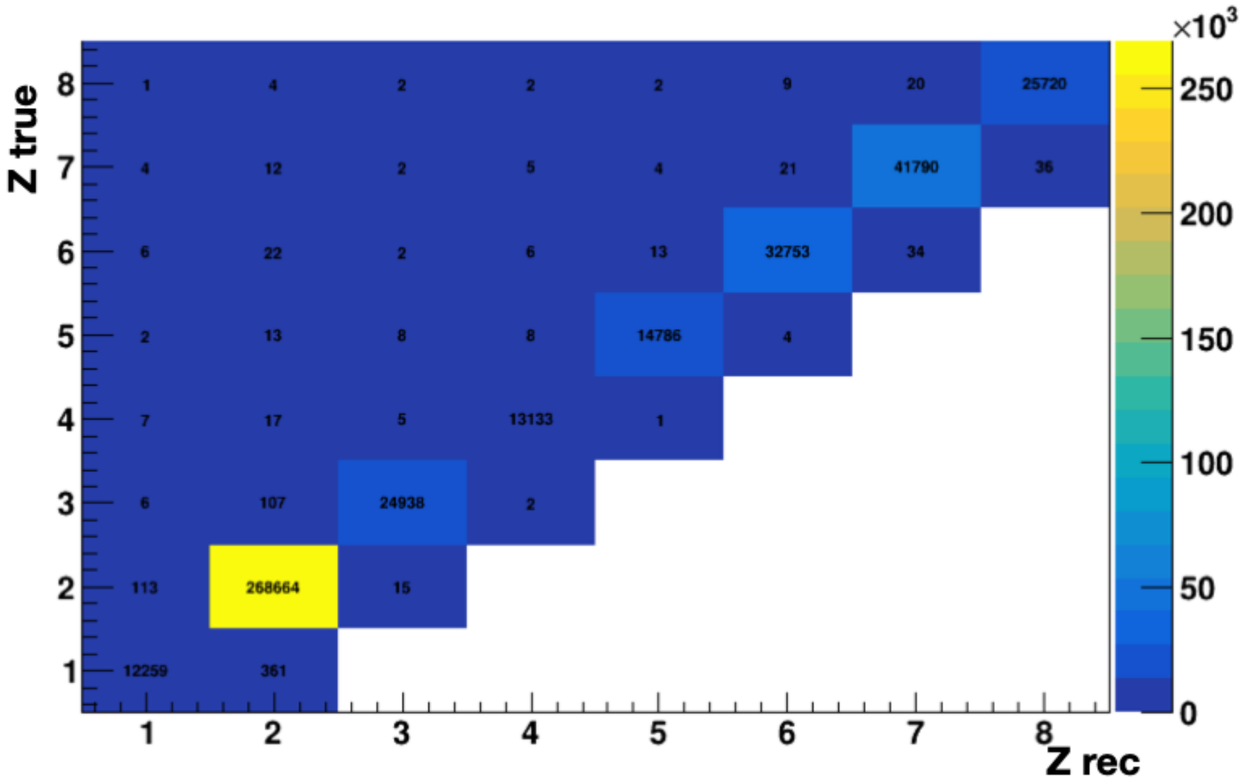


- Clustering algorithm associates hit bars in front and rear layer to reconstruct fragments impinging on TW
- Checking TW ZID+clustering algorithm comparing Eloss and Tof of hits matched to the cluster

TW algorihms performances

- It is possible to **correlate** in a charge mixing matrix the **reconstructed charge to the real one** (for MC truth).



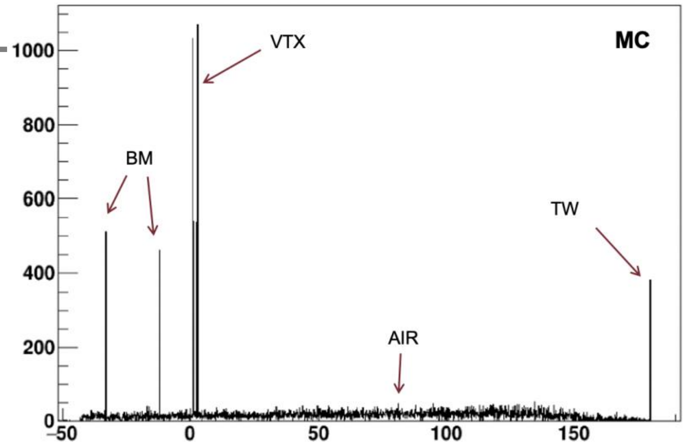
observe when the charge identification algorithm assigns a fragment to a wrong Z.

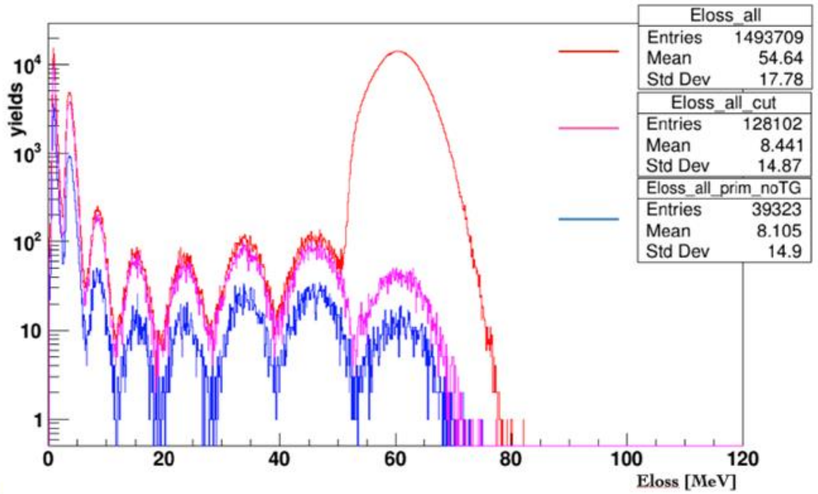
- It's almost **perfectly diagonal**: some charge mixed events in the region above the diagonal.

- This is a **good confirmation** that the charge identification and the clustering algorithms are able to identify efficiently the different Z fragment populations.

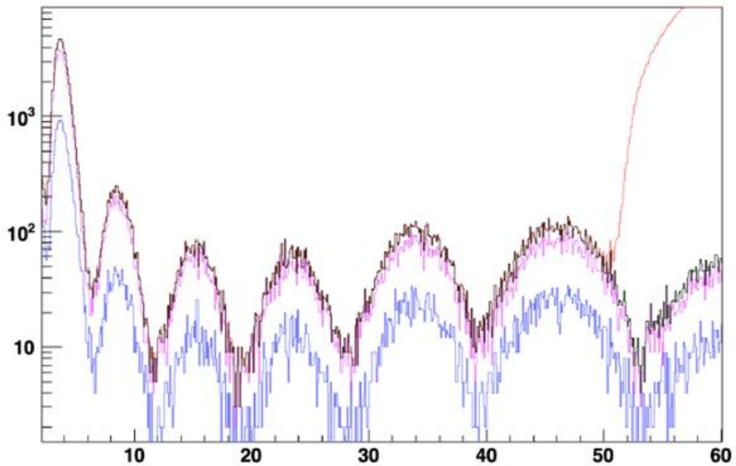
Background subtraction

- The fragments yields extracted by the TW detector mix **primary fragmentation produced in the TG**, which corresponds to the signal in the cross section measurements, and **primary fragmentation out of target** that results in a source of background for our measurement.





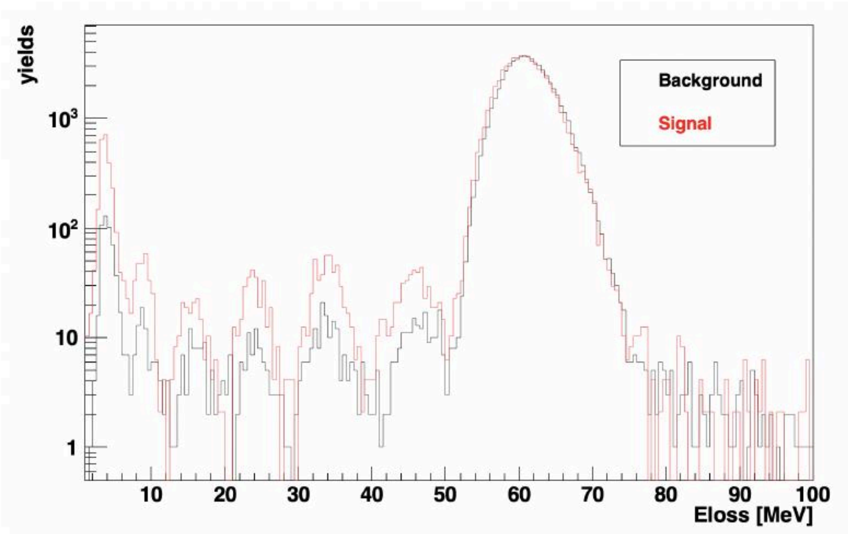
a



b

Background ~ **30%**

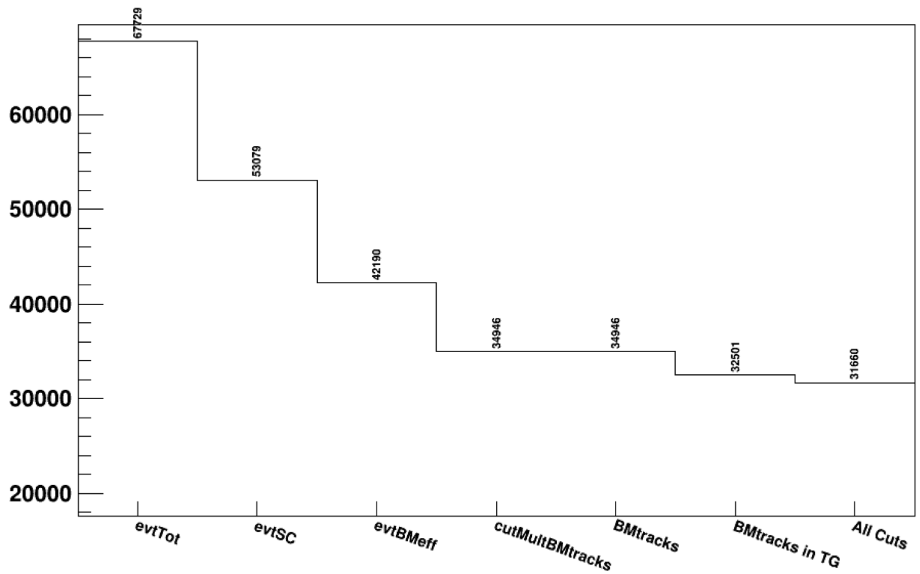
Background subtraction and yields extraction



Element	$Yields_{signal}$	$Yields_{bkg}$
N_{prim}	31660	61516
He	484 ± 22	1087 ± 33
Li	89 ± 9	152 ± 12
Be	73 ± 9	77 ± 9
B	88 ± 9	136 ± 12
C	156 ± 13	231 ± 16
N	207 ± 14	248 ± 16

- Background subtraction in data from runs 2210, 2211, 2212 without TG

$$\sigma(Z) = \frac{1}{N_{TG} \cdot \epsilon(Z)} \left[\frac{N_{TG}(Z)}{N_{TG}^{prim}} - \frac{N_{noTG}(Z)}{N_{noTG}^{prim}} \right]$$



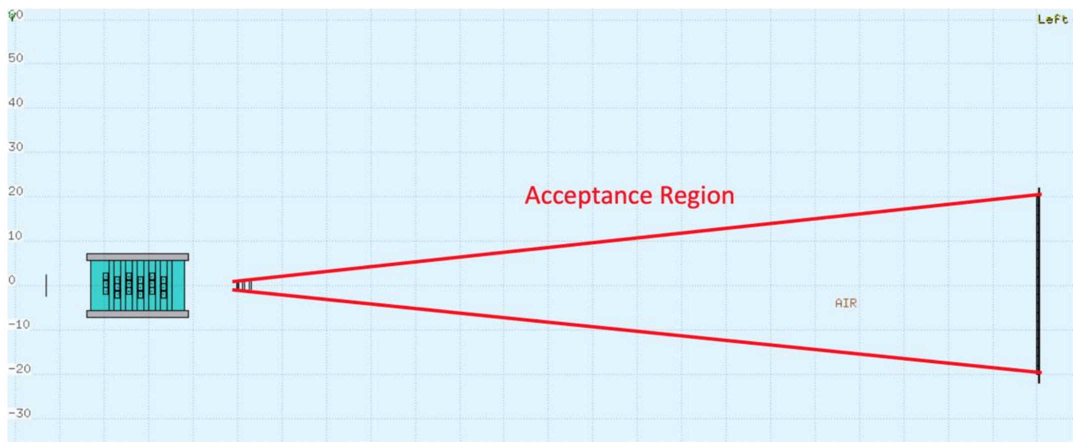
Reconstructed efficiencies

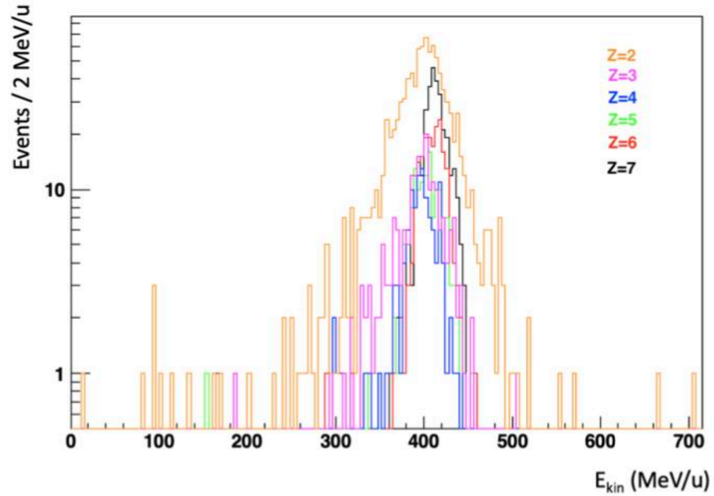
$$\epsilon = \frac{N_{TW}(Z)}{N_{prod}(Z)}$$

Numerator: asking for a good TW point matched to primary fragments with origin in Target with production angle < 5.7° and production E_{kin} in the range [100,600] MeV/u.

Denominator: asking for only primary fragments produced in Target and escaping from it with θ<5.7° and an E_{kin} in the range [100-600] MeV/u.

Element	Efficiency(%)
He	91.92 ± 0.05
Li	85.38 ± 0.20
Be	88.32 ± 0.26
B	88.75 ± 0.24
C	91.13 ± 0.15
N	95.88 ± 0.09





Charge-Changing cross sections

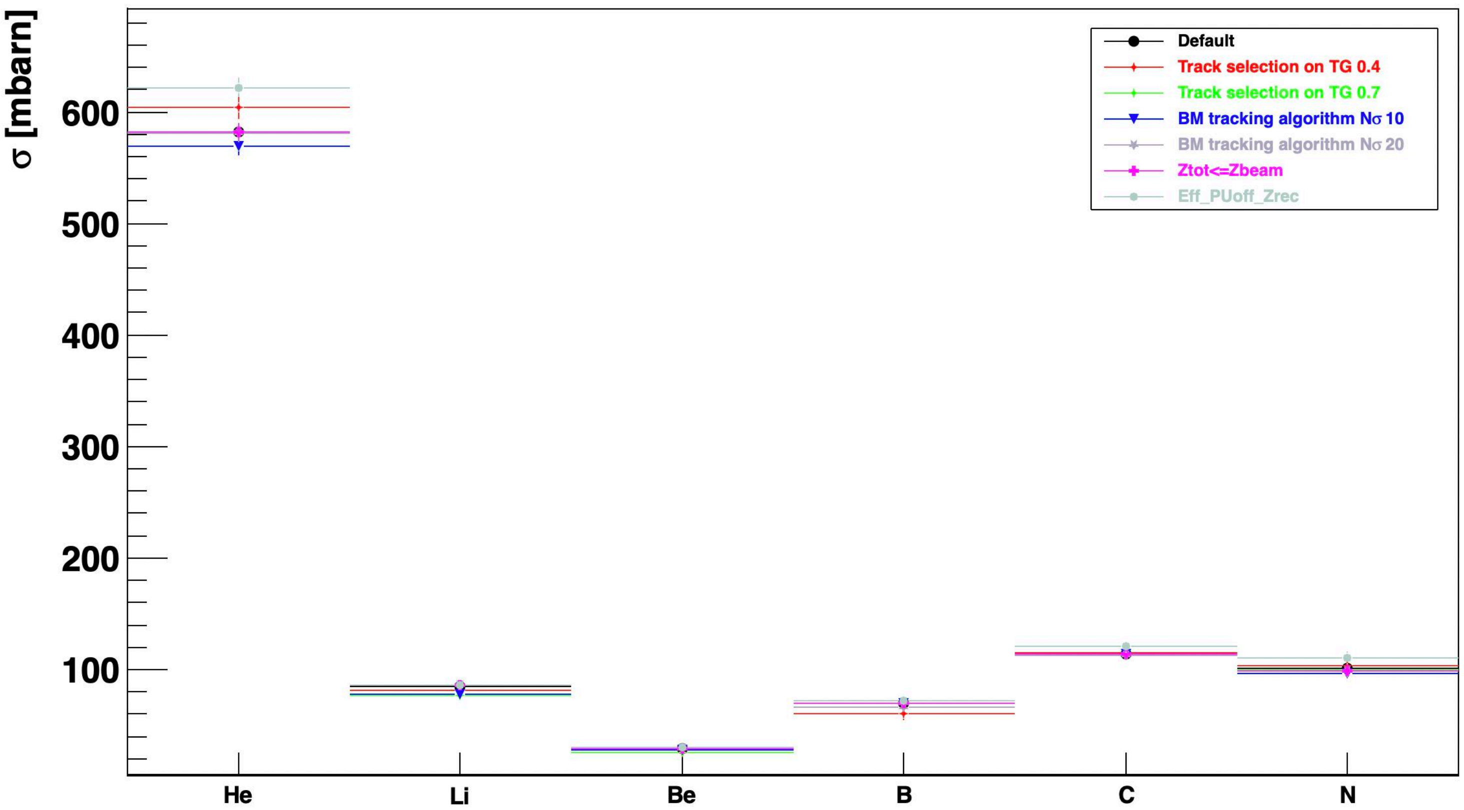
$$\sigma(Z) = \int_{E_{min}}^{E_{max}} \int_0^{\Delta\theta} (\frac{\partial^2 \sigma}{\partial\theta \partial E_{kin}})\, d\theta dE_{kin} = \frac{N_{frag}(Z)}{N_{prim} \cdot N_{TG} \cdot \epsilon(Z)}$$

$$N_{TG} = \frac{\rho \cdot dx \cdot N_A}{A} \quad \begin{cases} \rho = 1.83\ g/cm^3 \\ dx = 0.5\ cm \\ A = 12.0107 \end{cases}$$

$$\sigma(Z) = \frac{1}{N_{TG} \cdot \epsilon(Z)} [\frac{N_{TG}(Z)}{N_{TG}^{prim}} - \frac{N_{noTG}(Z)}{N_{noTG}^{prim}}]$$

Element	$\sigma_{frag} \pm \Delta_{stat} \pm \Delta_{sys}[mbarn]$	$\Delta_{stat}/\sigma_{frag}$	$\Delta_{sys}/\sigma_{frag}$	$\sigma_{MC}[mbarn]$
He	$625 \pm 22 \pm 21$	3.6%	3.6%	621
Li	$85 \pm 10 \pm 5$	11.9%	5.6%	67
Be	$31 \pm 10 \pm 3$	31.8%	8.8%	33
B	$70 \pm 10 \pm 5$	14.9%	7.3%	38
C	$113 \pm 12 \pm 3$	10.9%	2.7%	81
N	$101 \pm 14 \pm 5$	13.7%	4.8%	105

Charge-Changing cross sections



1. Different **selection criteria of the projection** of the beam direction **on TG**;
2. Quality of the **BM reconstructed tracks**;
3. Charge of the **reconstructed point ≤ charge of the beam**;
4. Charge **reconstruction algorithm** in the fragments' identification.

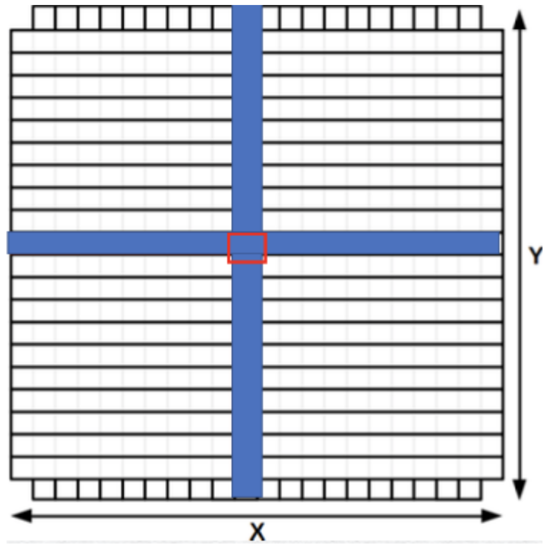
Trigger implementation

- Limited acquisition rate of the experiment → **Goal:** select the interesting fragmentation events introducing a Trigger on data using TW detector

1 kHz → Low statistic

- 1^{st} **TW trigger:** introduce in the MC a threshold in energy loss on the central bars of the TW detector;

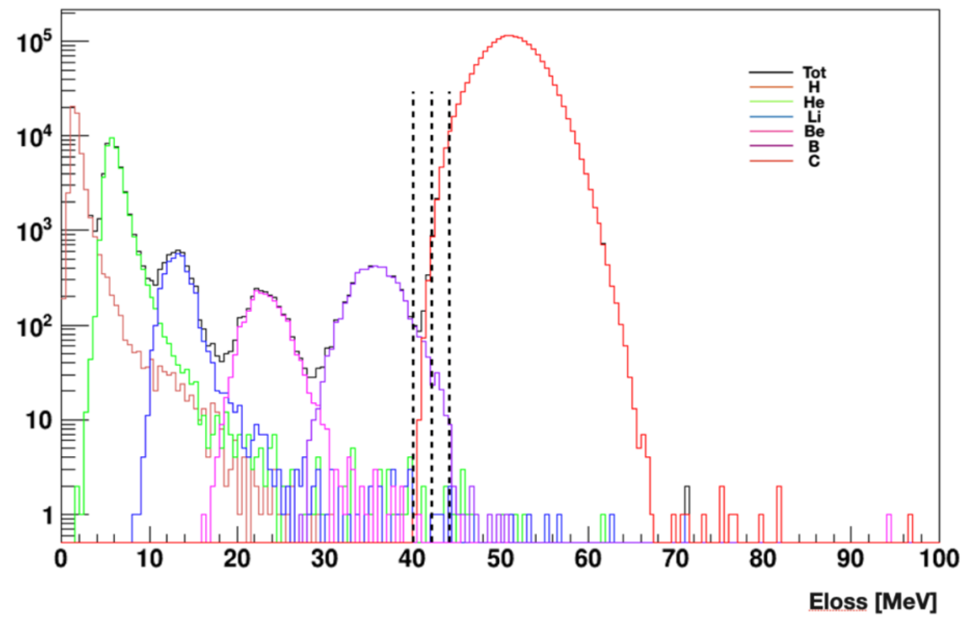
- 2^{nd} **TW trigger:** require another hit somewhere in TW when there is a signal from central bars.



^{12}C (200 MeV/u) → C_2H_4
2 * 10^6 events

1^{st} TW Trigger

- Using TW Eloss distributions we have choosen 3 different thresholds to study:
  1. Eloss = 38 MeV;
  2. Eloss = 42 MeV;
  3. Eloss = 46 MeV.



- We take all fragments arriving on the TW **except the ones hitting the central bars** with **energy loss above the threshold**.
- Trigger Efficiencies: $\frac{N(Z)_{TW}}{N(Z)_{MB}}$

Element	Thr = 38 MeV	Thr = 42 MeV	Thr = 46 MeV
B	97.32%	99.74%	100%
C	1.40%	1.45%	9.33%

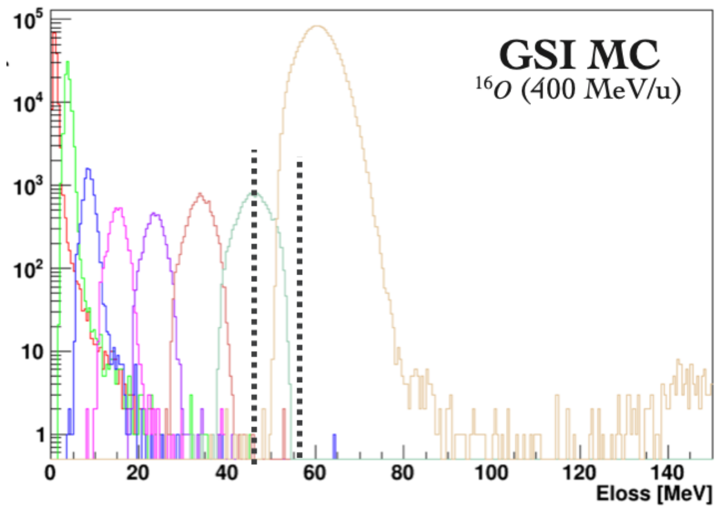
Fraction of primaries selected with this TW trigger with respect to the MB trigger

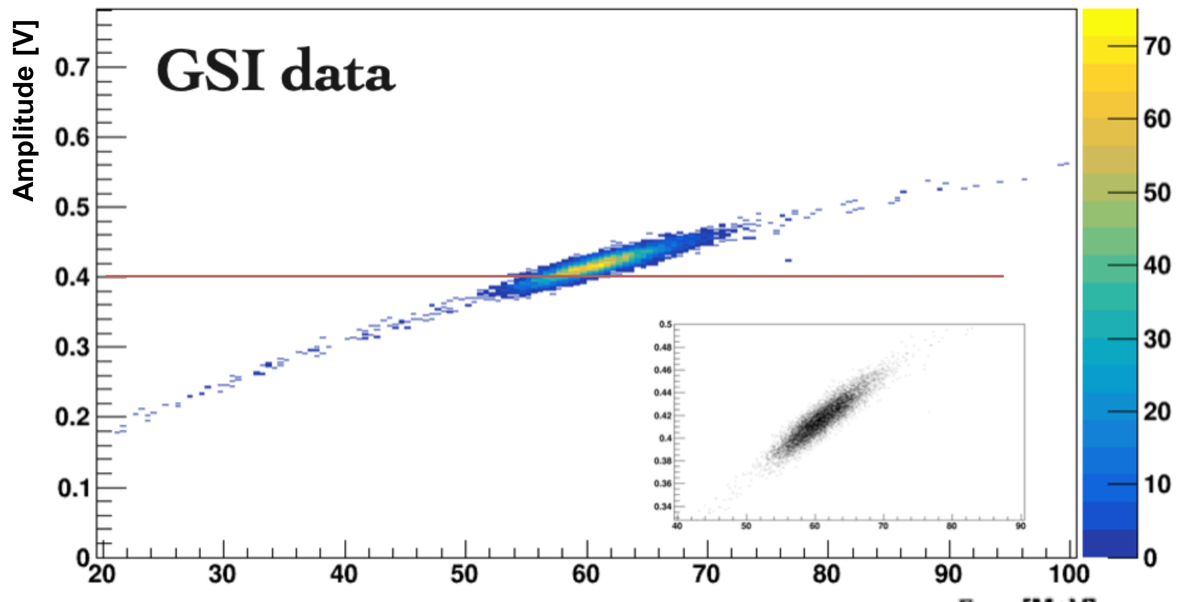
1^{st} TW Trigger

- **Choice of the threshold**: a compromise between the number of fragments we want to take and the bias that will be introduced.

- From the **hardware point of view** the threshold in Eloss must be translated in a signal amplitude threshold

- Fix an amplitude threshold means to take an **energy loss range** of about **4-5 MeV**.





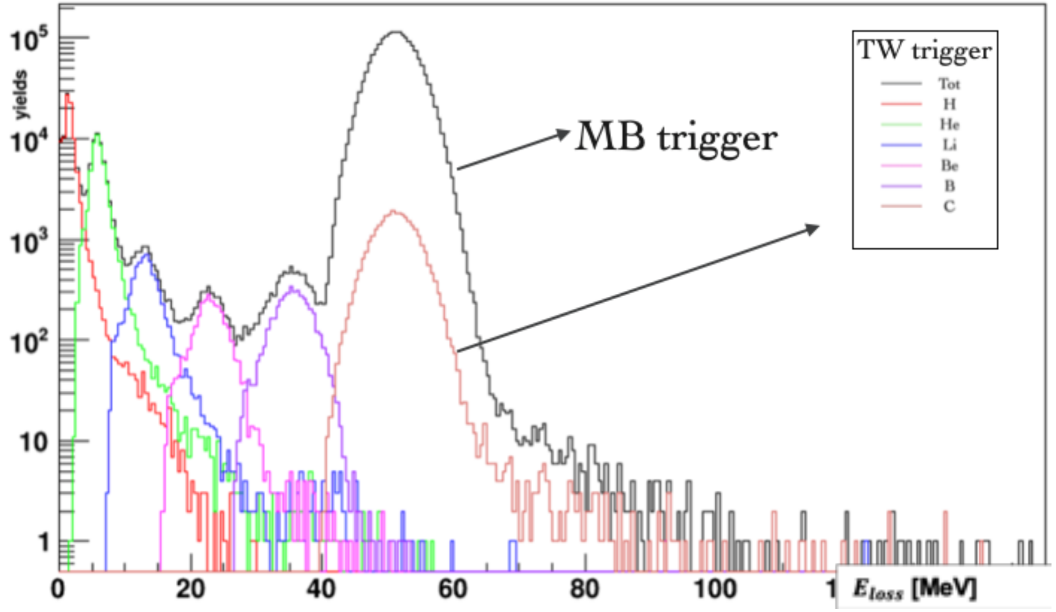
Ex: Amp = 0.4 V -> = 54-58 MeV

2^{nd} TW Trigger

- We count the hits on the central bars only if there is **another hit** somewhere in the TW.

- Trigger Efficiencies: $\frac{N(Z)_{TW}}{N(Z)_{MB}}$

Element	Efficiencies
H	98.06%
He	95.23%
Li	92.19%
Be	85.45%
B	58.09%
^{12}C	1.66%



- The **bias** we will introduce on the fragments (especially on B) **is more significant** with respect to the other trigger.

Choice of the trigger

1^{st} TW Trigger

- Very small bias introduced for B (and C fragments).
- Compromise between few % systematics trigger bias and amount of primaries acquired (1% → 10%).

2^{nd} TW Trigger

- Greater bias (to evaluate properly acquiring MB events).
- Low amplitude thresholds have to be set to remove noise (in order not to take as good events primary+noisy hit somewhere in TW).

From these observation **the first TW trigger** could be **the favorite** choice employing an high threshold in order to minimize the bias and manteining a good primaries rejection power.

Conclusions

- Preliminary measurement of the GSI cross section O+C at 400 MeV/n has been shown

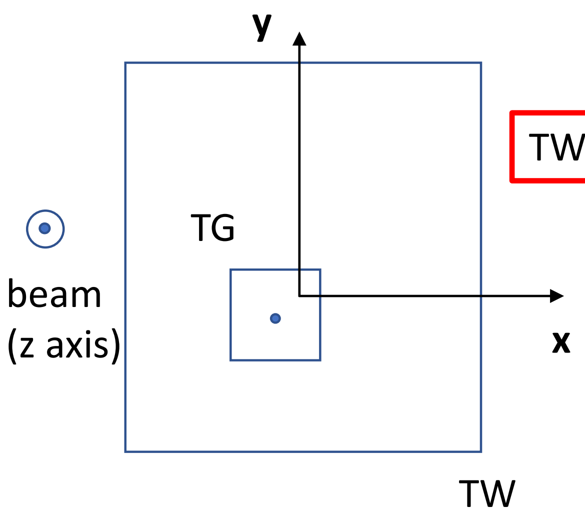
- Some algorithms developed in SHOE for this analysis, useful for the future

- Trigger implementation to be use during the next data acquisitions (GSI 2021)

Paper in preparation to be submitted on the JINST journal

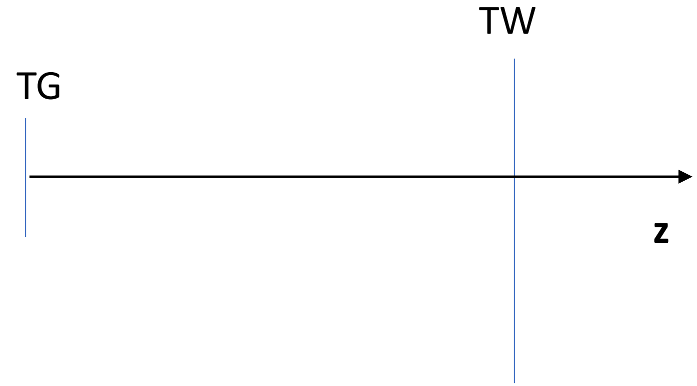
Spare slides

Angular acceptance



TW center glb ~ [-1,-1]

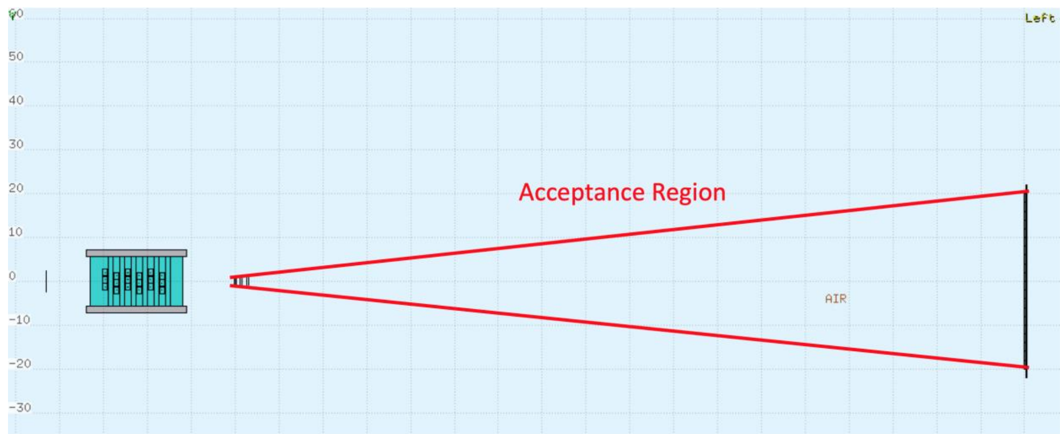
Small shift between BM and TW



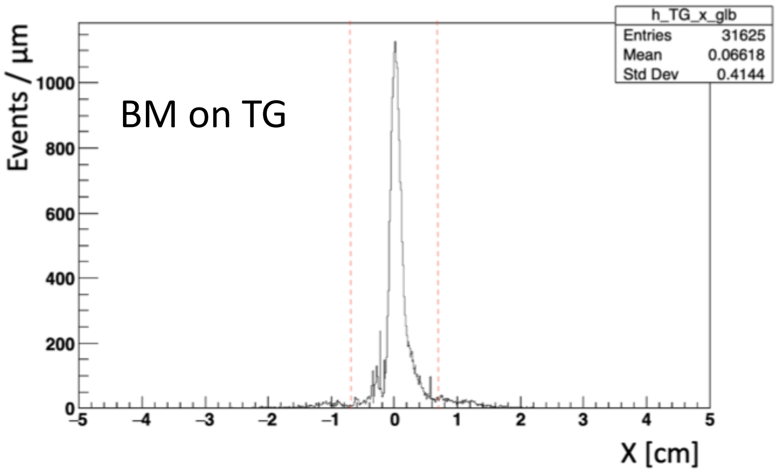
$0° \leq \theta \leq 5.7°$

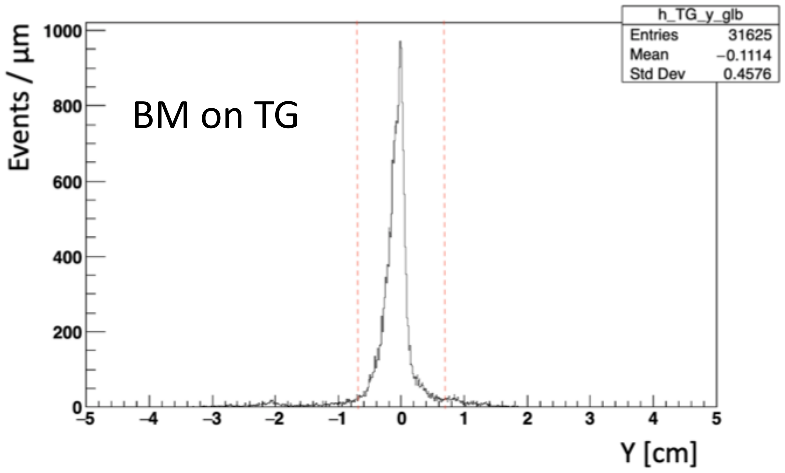
$0° \leq \varphi \leq 360°$

Selecting fragments from TG region [-0.7,0.7] cm

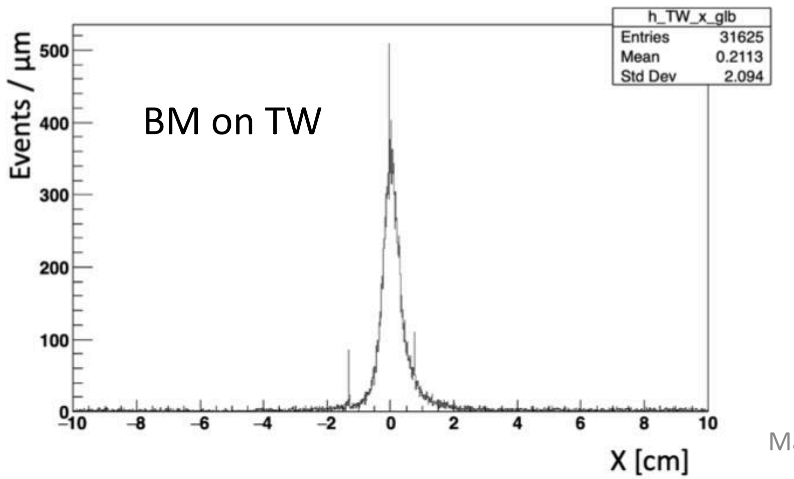


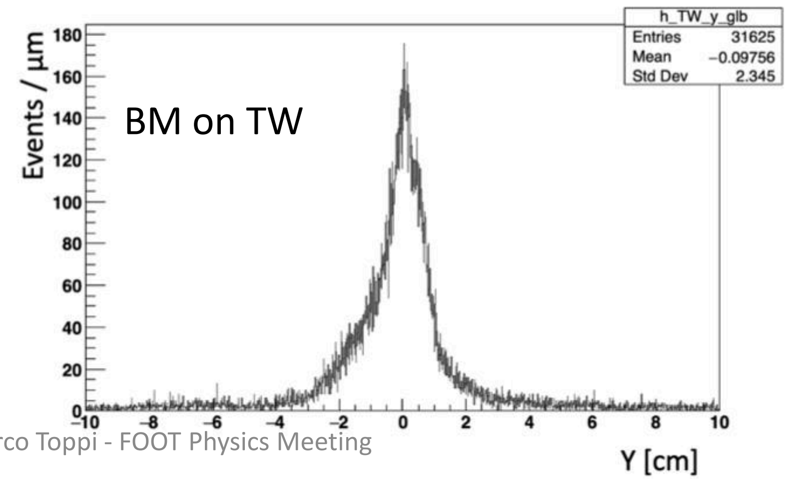
Beam and Beam Monitor at GSI





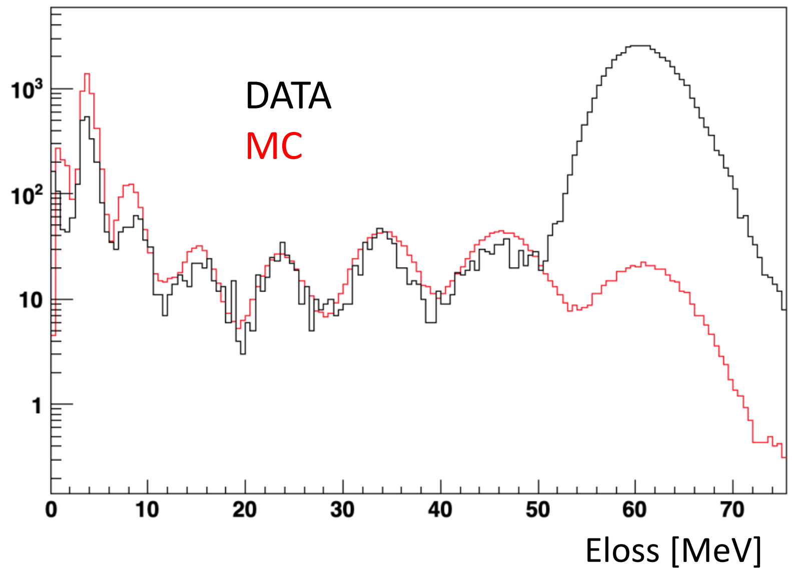
The beam structure, even if not Gaussian, is centered at (x,y) = (0,0) in the global reference frame

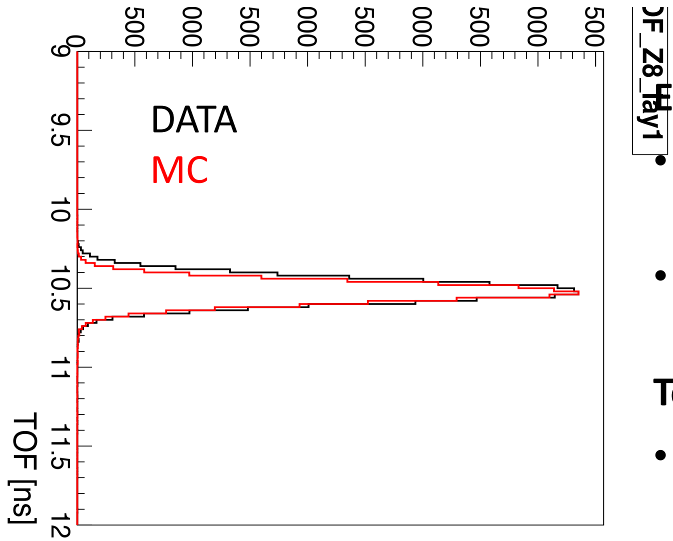




The broadening of the distribution on the TW shows a divergence of the beam of ~ 5 mrad (about 0.3°) in X and Y → to be considered in systematics

Calibration and tuning of MC on GSI DATA





Eloss Calibration:

- "Tuned" and applied CNAO Pisa-calibration to GSI data
- Cross-checked with a GSI standalone calibration

ToF calibration:

- Calibration from 2242 for runs 2239,2240,2241
- Standalone calibration for run 2251

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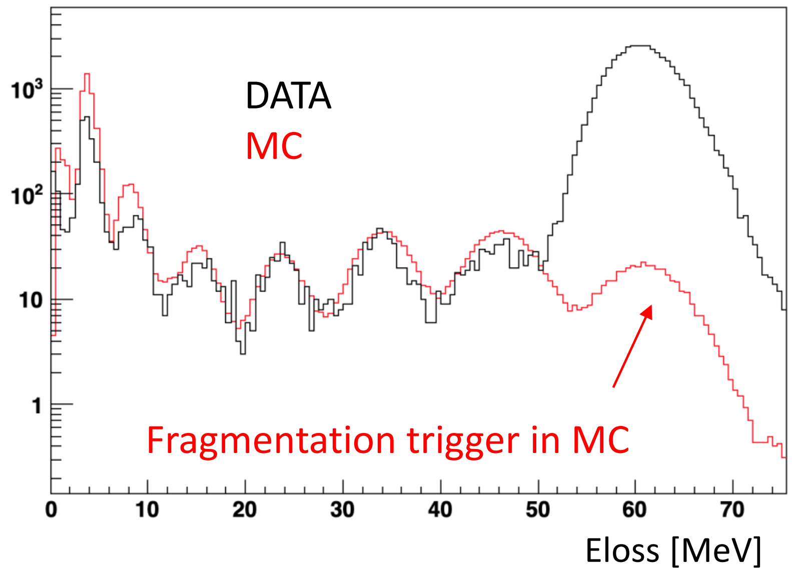

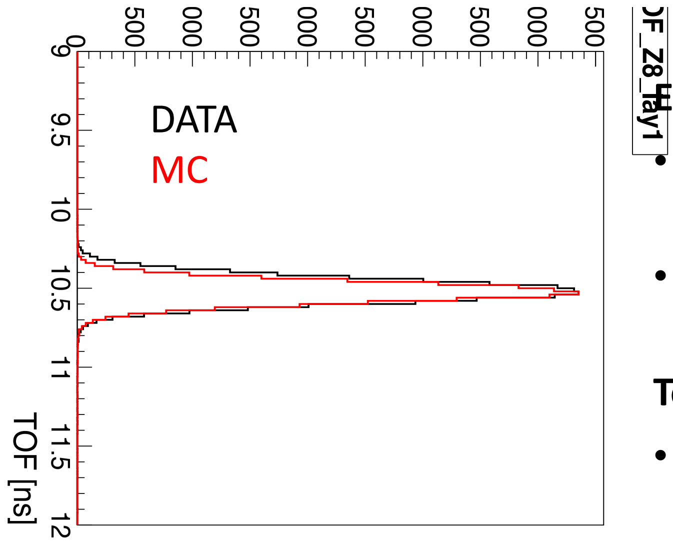

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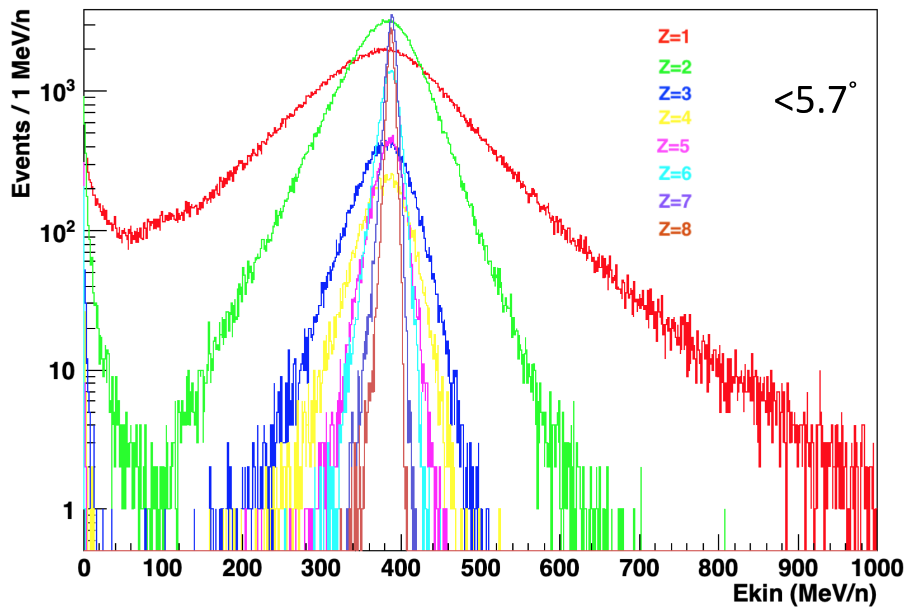
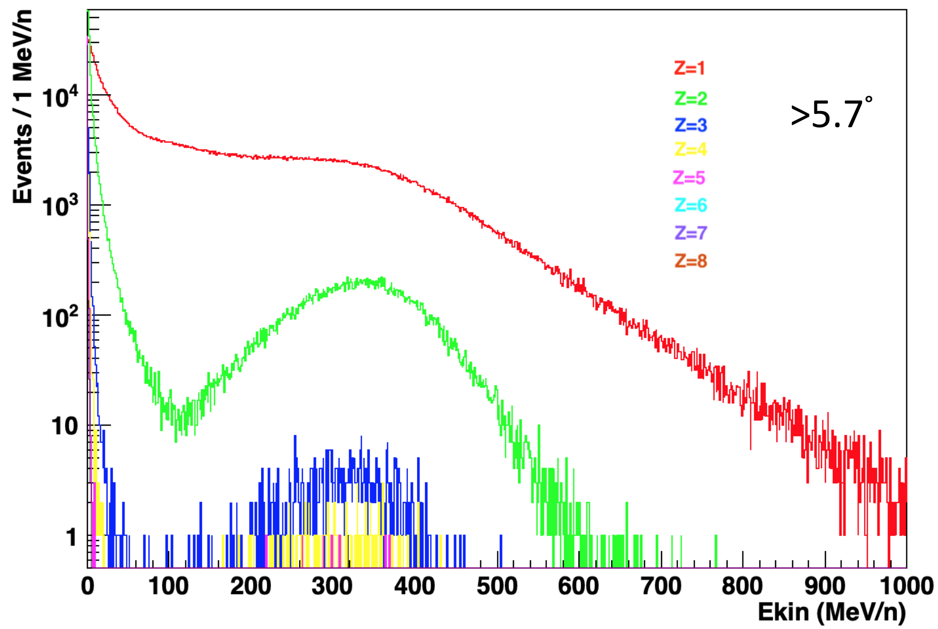
In SHOE implemented reconstructed MC takes into account:

- Eloss, Tof and t_{TW} resolutions from CNAO data. Eloss threshold (cut away most of the protons) and dead bars @ GSI
- Time and position reconstruction from times Ta and Tb (data-like)
- Pile-up (multi-hit in the same bar per event) and fragment charge from ZID algorithm.

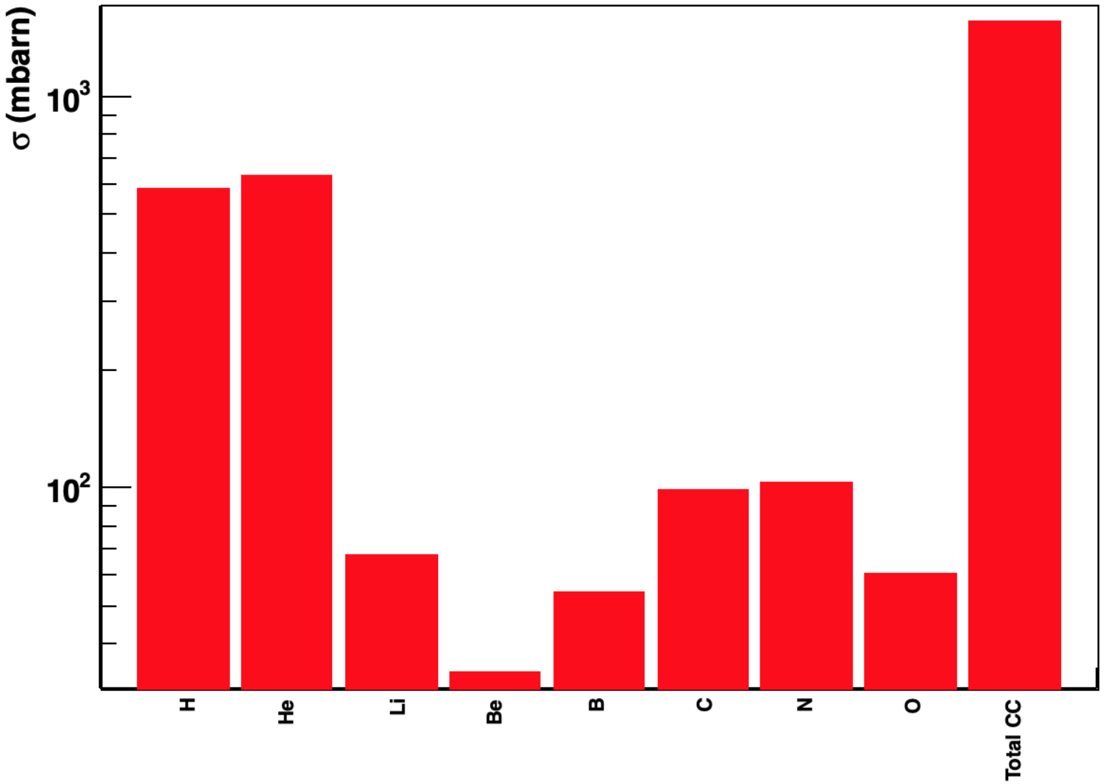
FLUKA: E_{kin} distribution fragments in TG





Asking for only primary fragments with origin in Target

$\sigma_{Production}$ in TG (between 0° and 5.7°)

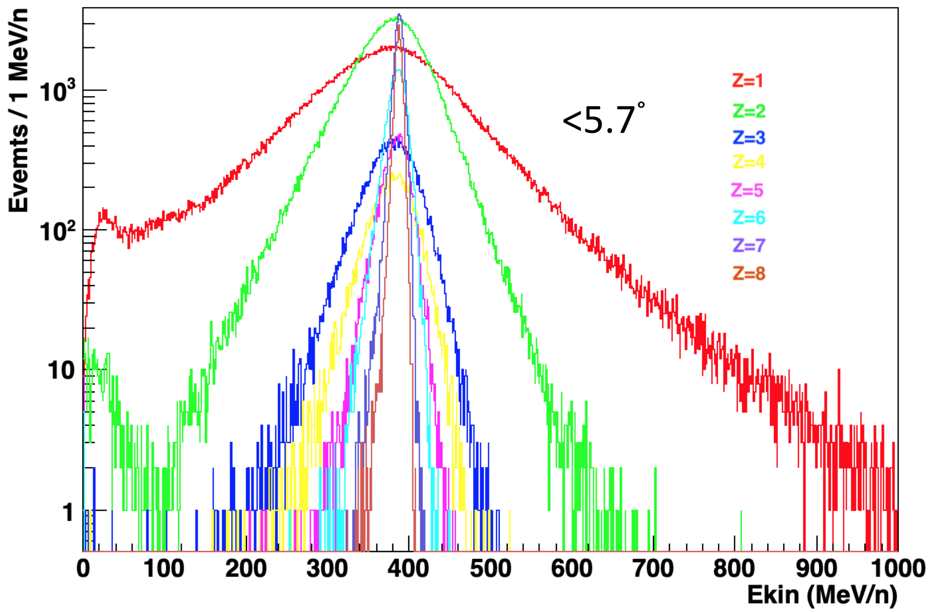


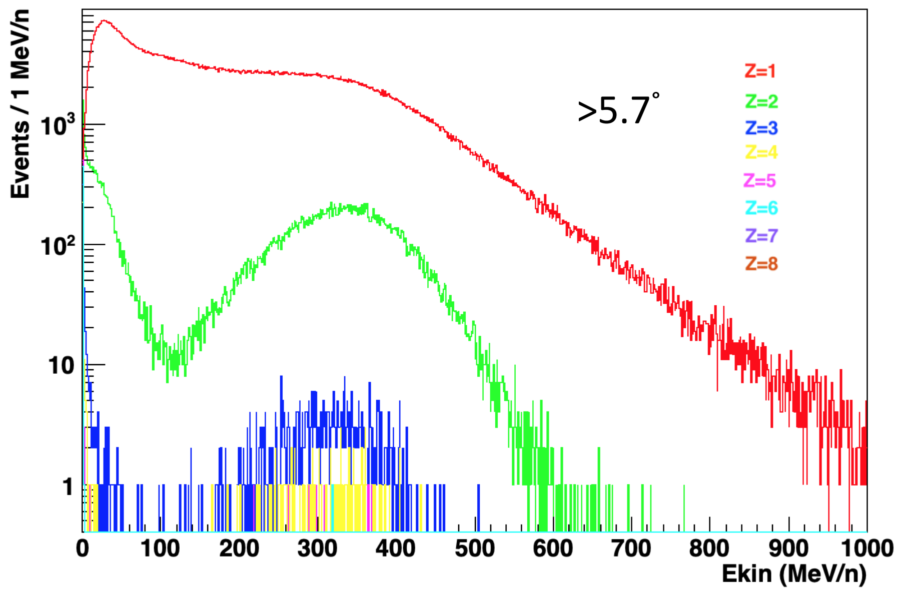
$$\sigma = \int_{0°}^{7°} \frac{d\sigma}{d\theta}|_{0°-7°} d\theta = \frac{N_f}{N_{oxy} * N_t}$$

Where: $N_t = \frac{\rho * dx * N_A}{A}$

Charge	Cross section (mbarn)
1	582.237098
2	624.328050
3	67.443612
4	33.971387
5	54.391275
6	98.731728
7	103.810543
8	60.529448
Total CC	1564.913692

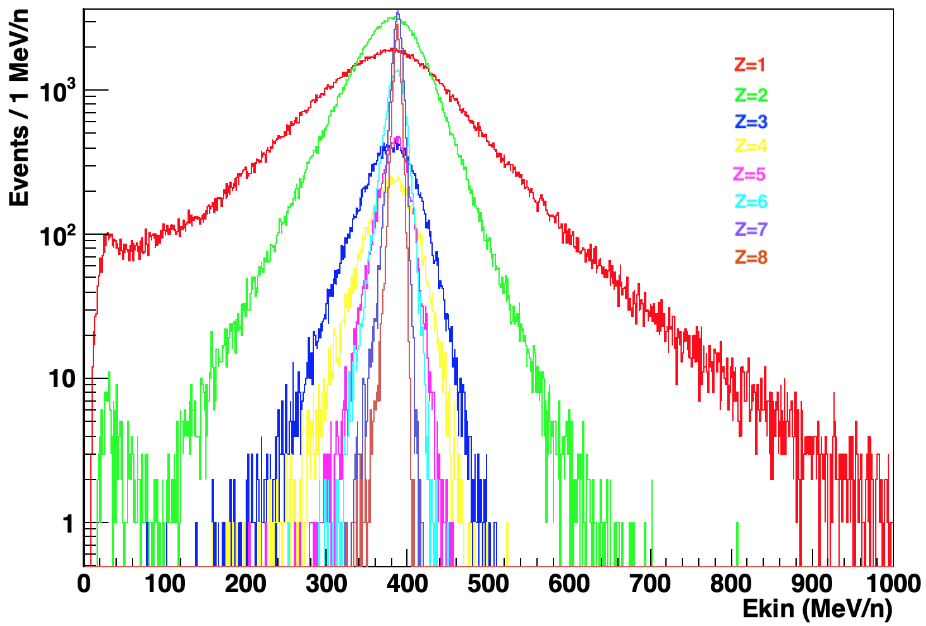
E_{kin} distribution fragments out TG





Asking for only primary fragments with origin in Target produced on the TG in [-0.7,0.7].

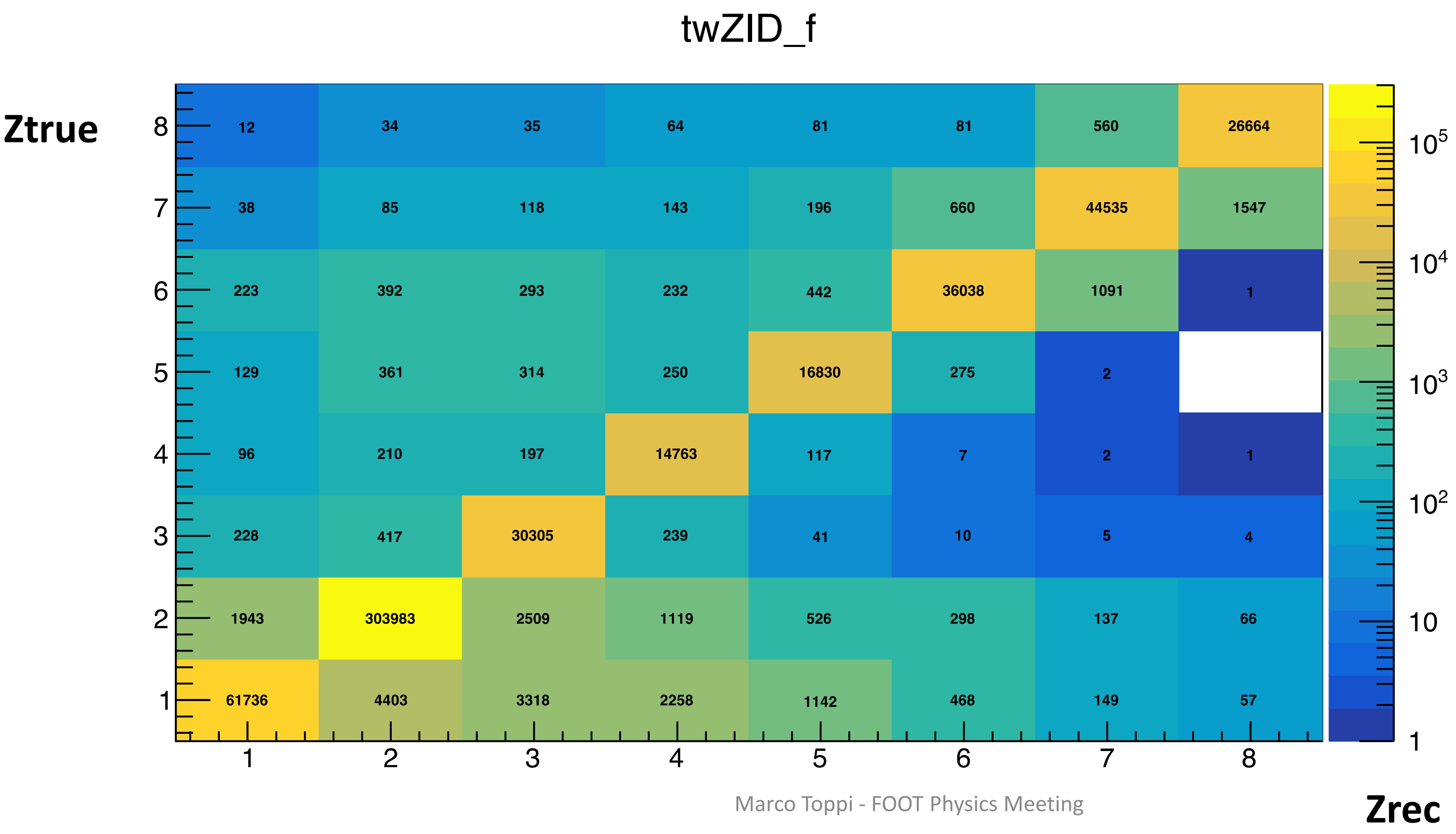
E_{kin} distribution TW hit



E_{kin} production

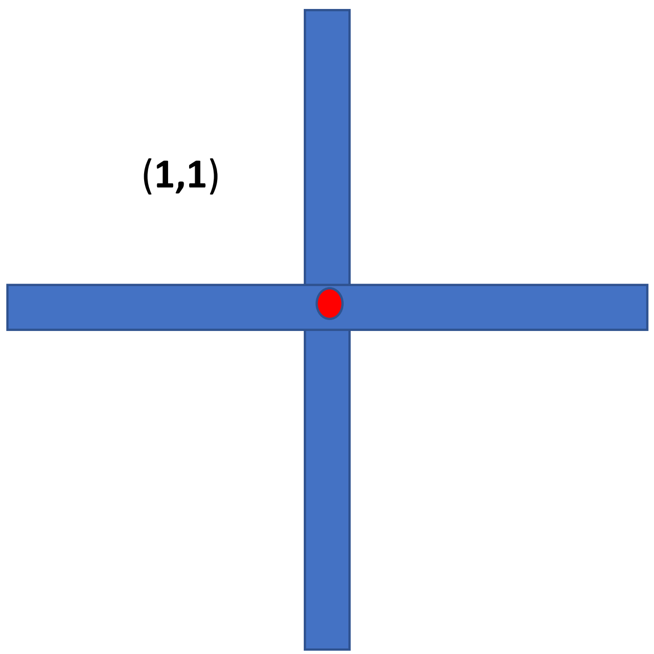
Asking for only primary fragments with origin in Target (over threshold) with production angle < 5.7° and beam progection on TG in [-0.7,0.7] matching a TW hit

Charge mixing matrix for TW hits



Yields extraction and TW Clustering

In order to extract fragment yields from cross sections measurement front and rear TW hits have to be clusterized.
New algorithm implemented in SHOE.



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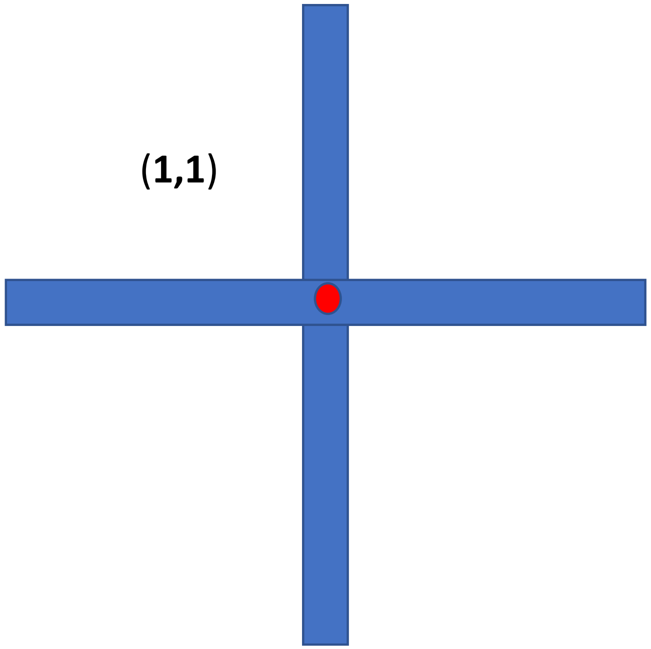
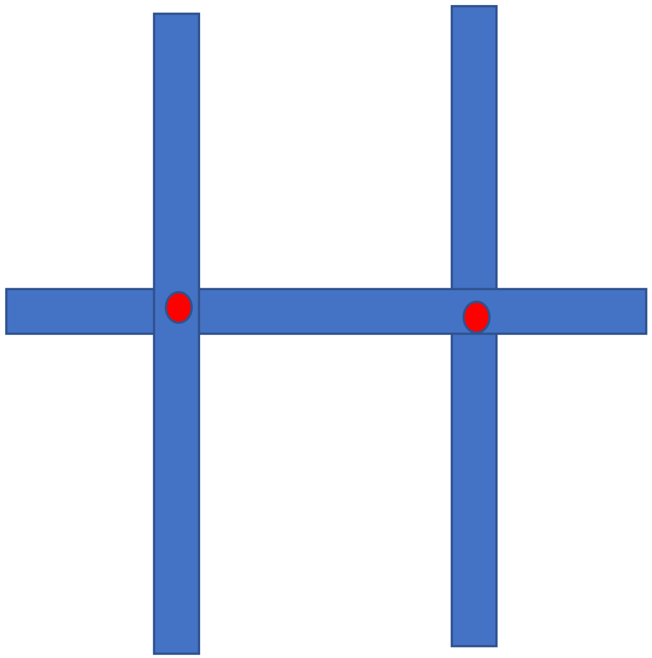
(1,1)



(1,N), (N,1), with N>1



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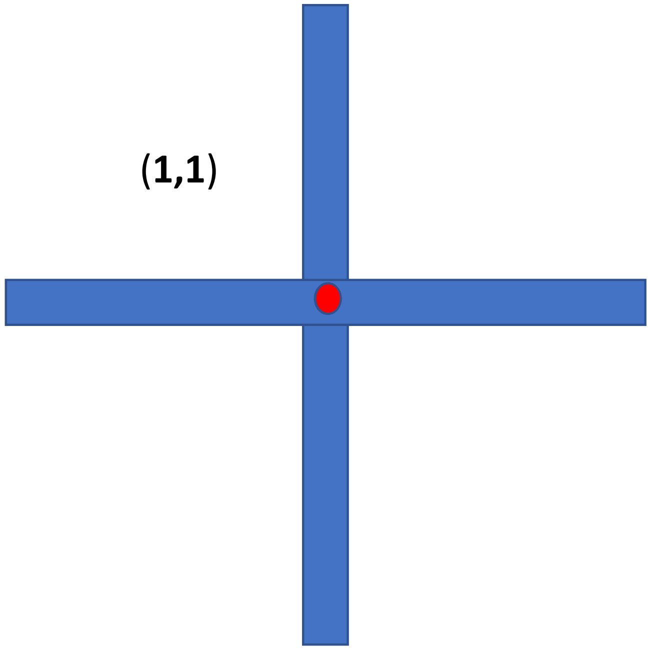
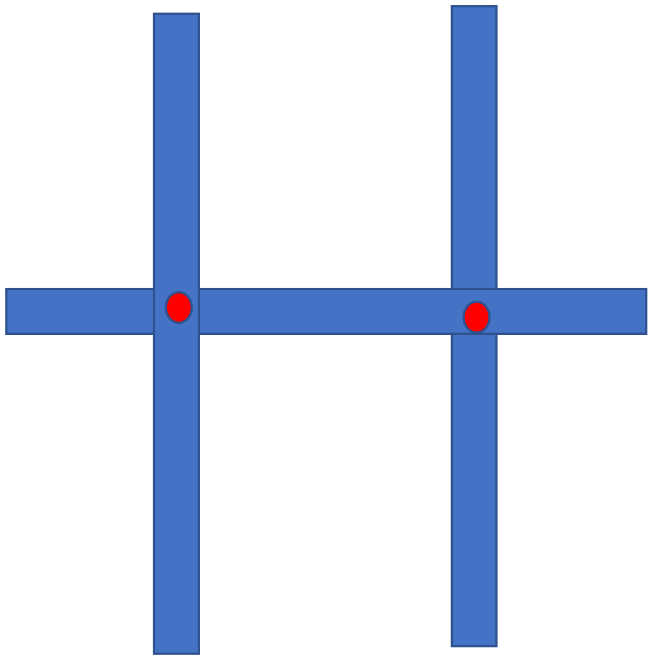
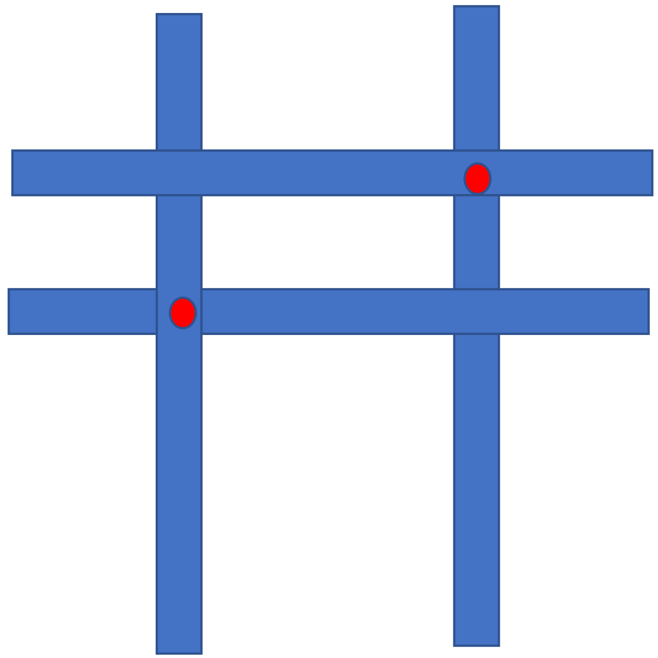


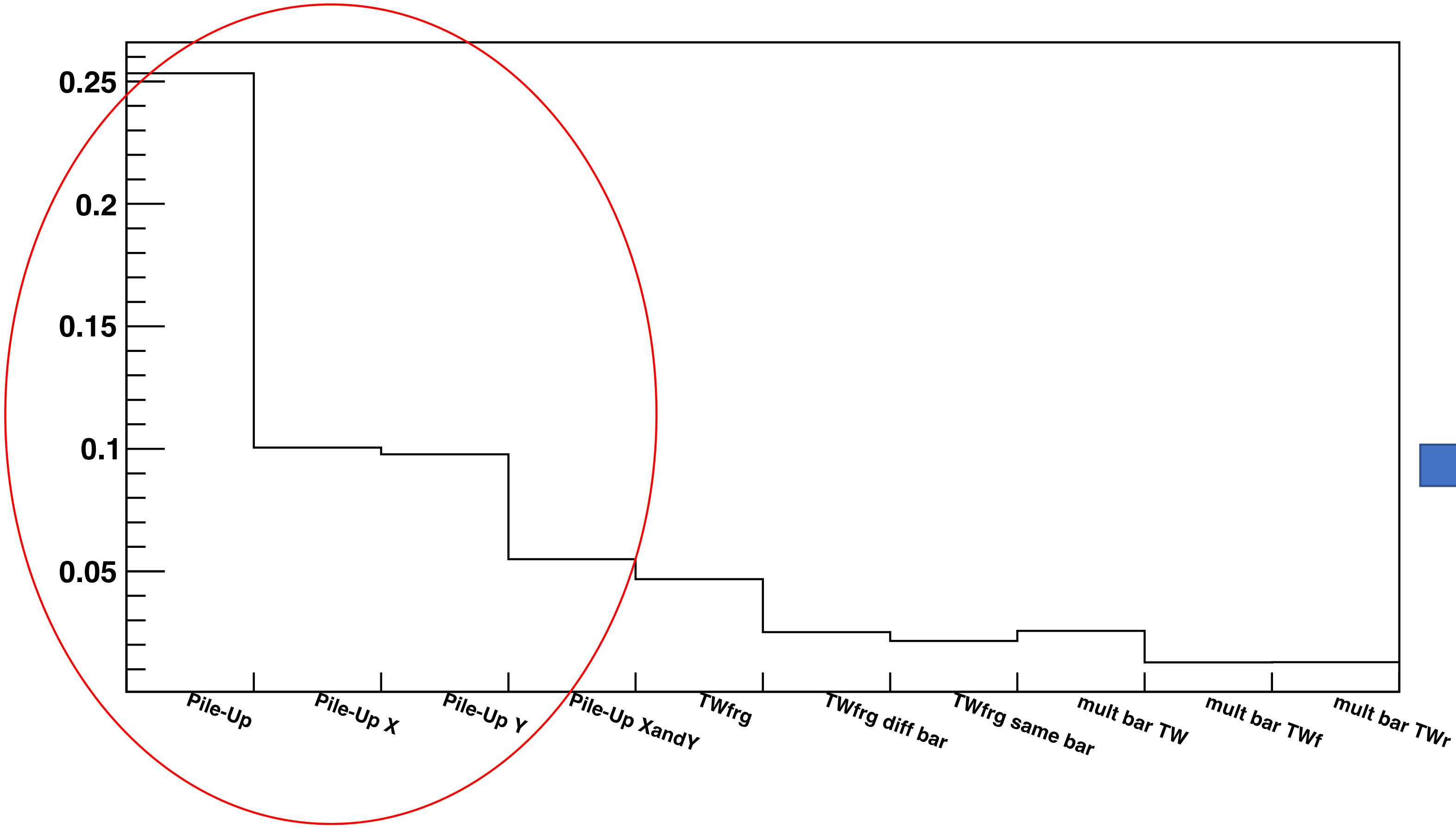
(1,N), (N,1), with N>1



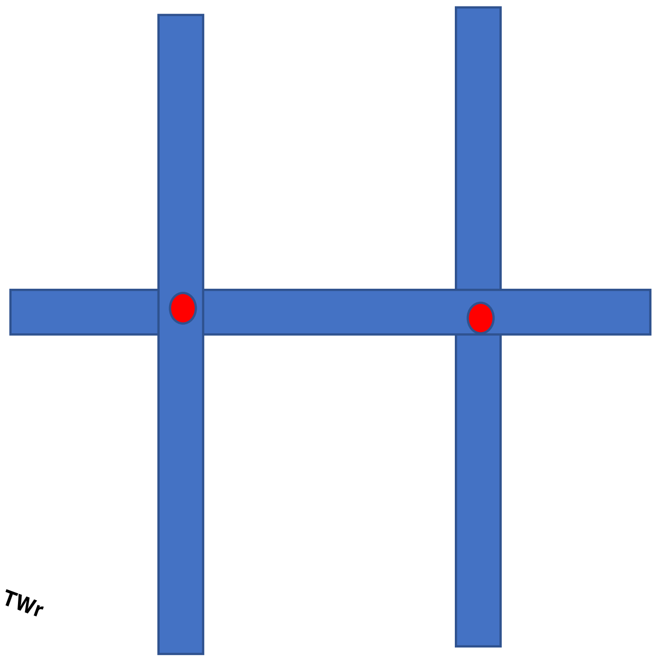
(N,M), (M,N), with N,M>1



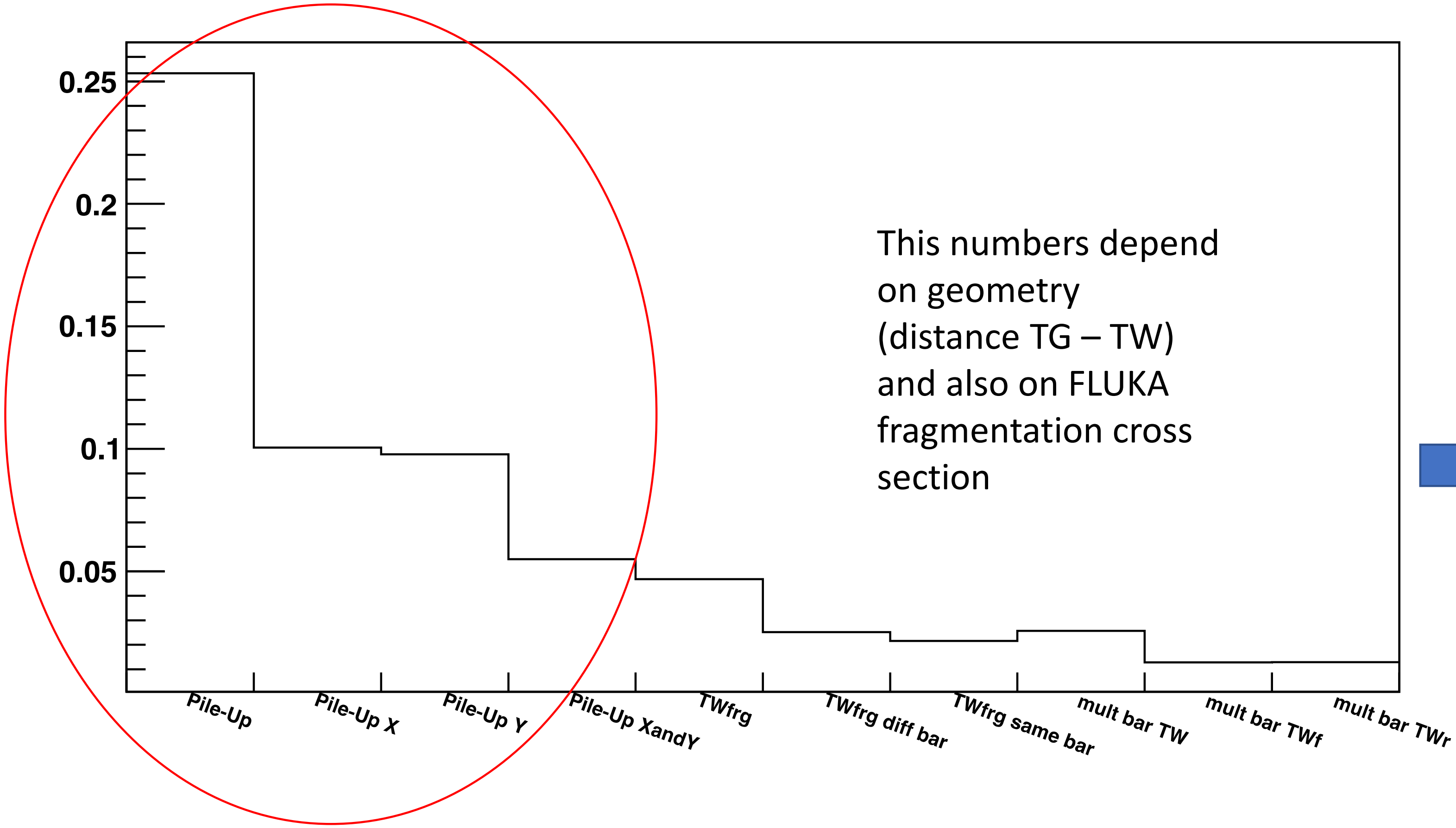
Yields extraction and TW Clustering



Pile-Up (multi-hits)

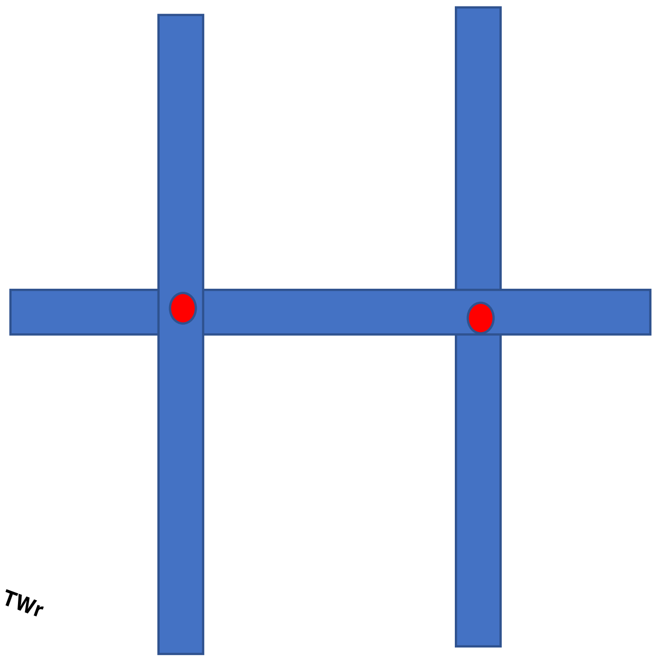


Yields extraction and TW Clustering

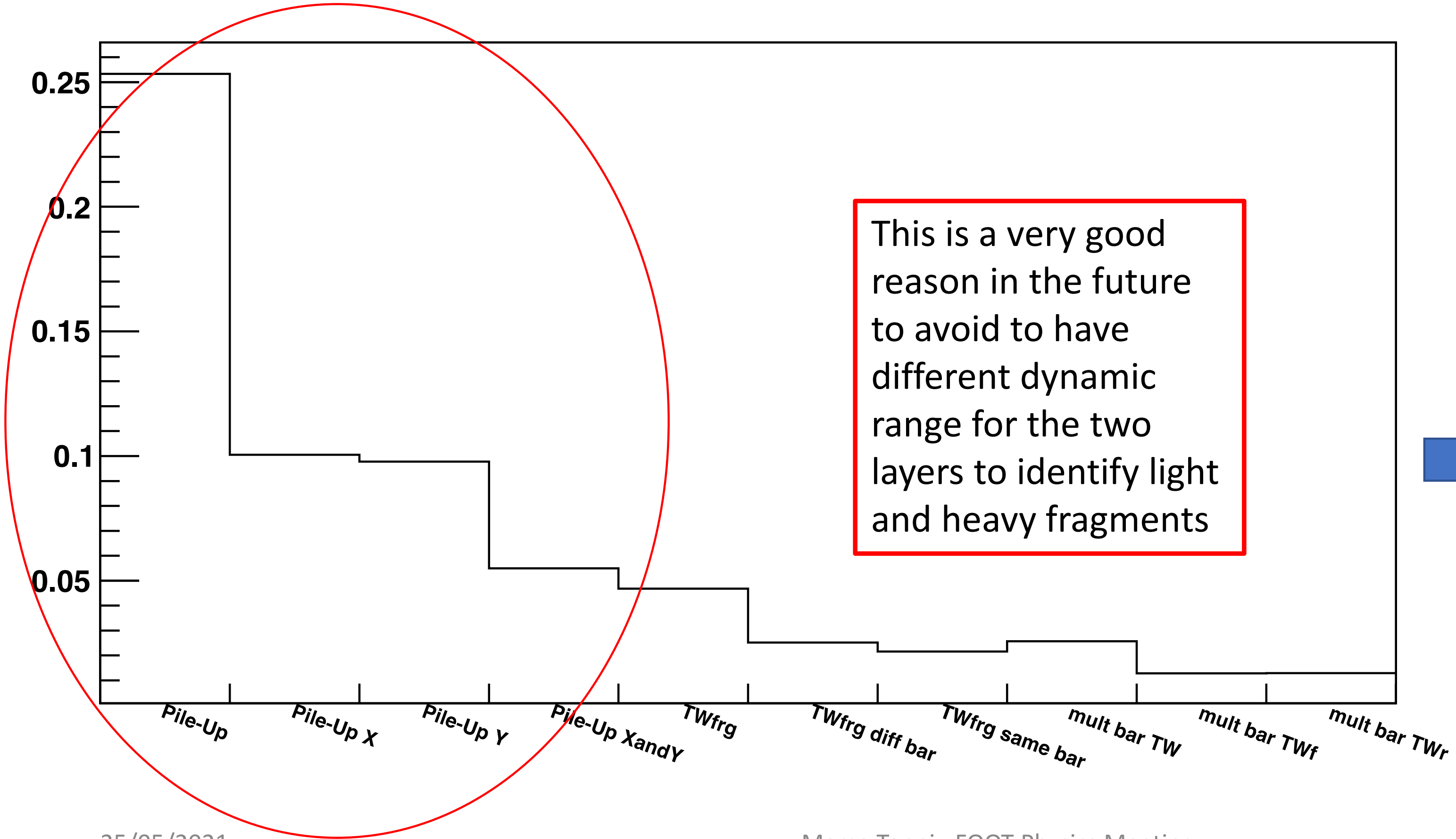


This numbers depend on geometry (distance TG – TW) and also on FLUKA fragmentation cross section

Pile-Up (multi-hits)

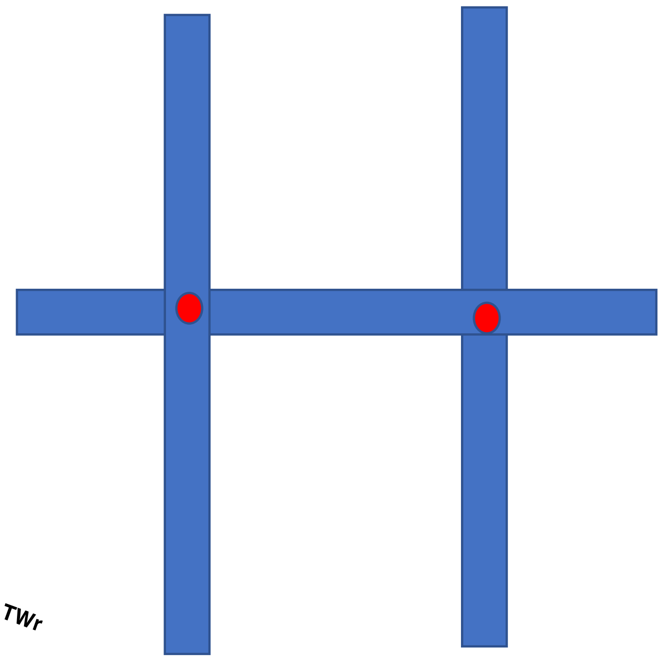


Yields extraction and TW Clustering

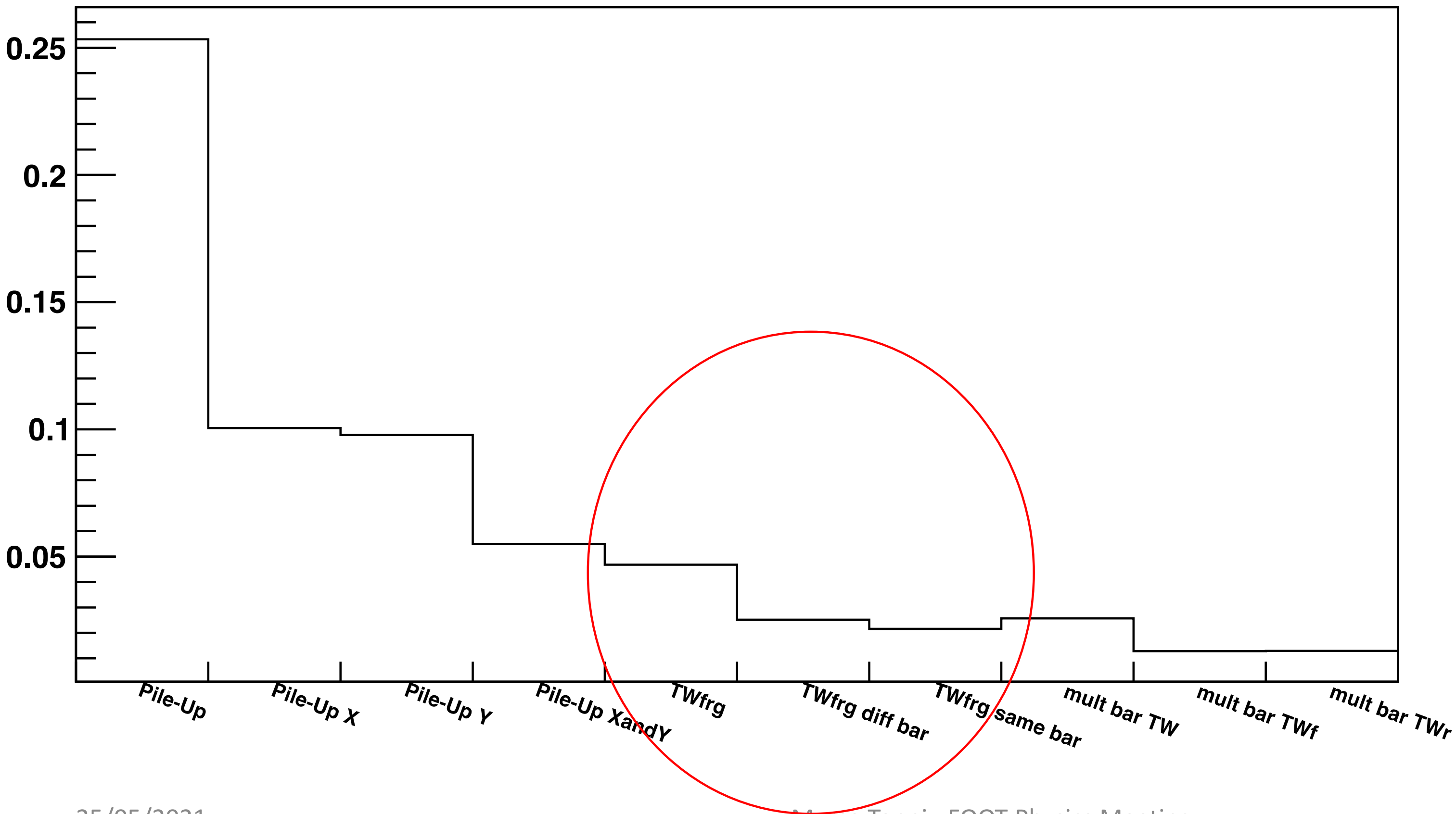


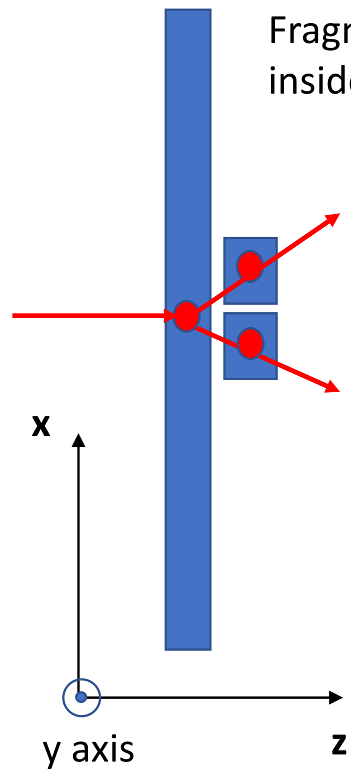
This is a very good reason in the future to avoid to have different dynamic range for the two layers to identify light and heavy fragments

Pile-Up (multi-hits)



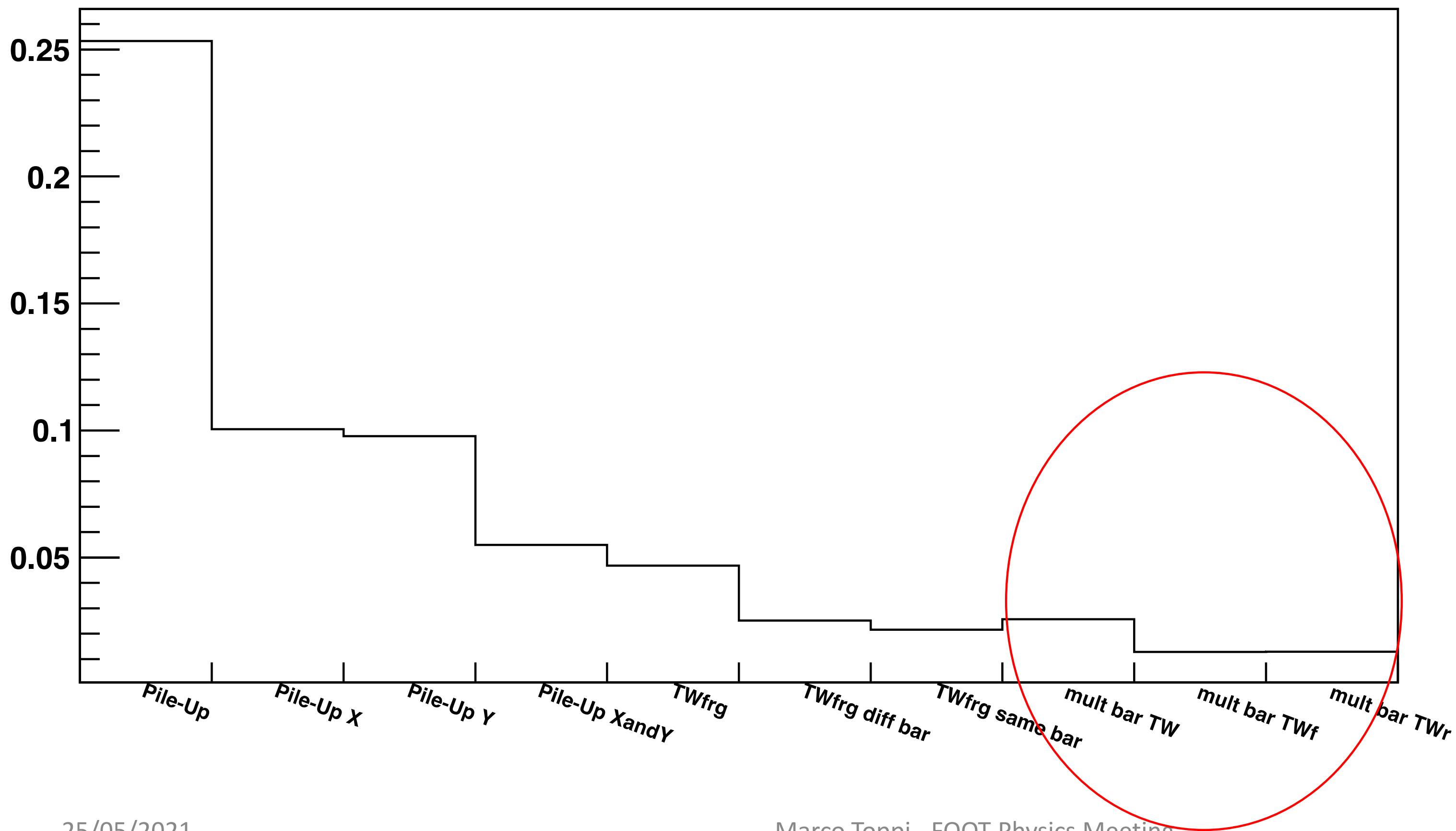
Yields extraction and TW Clustering

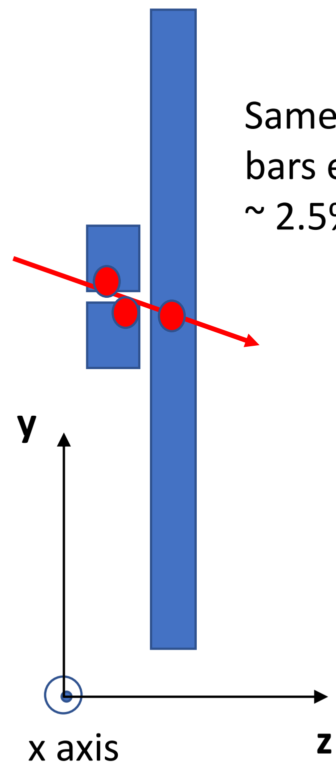




Fragmentation inside TW ~ 2.5%

Yields extraction and TW Clustering

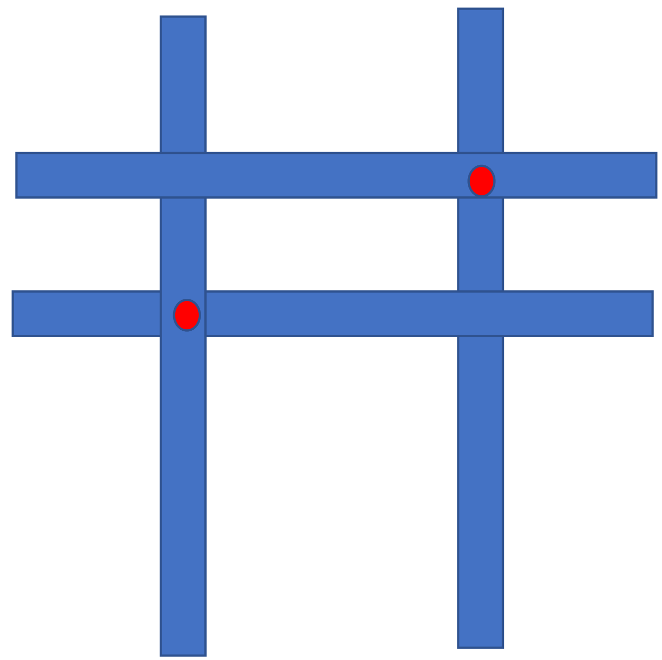




Same layer multi-bars events ~ 2.5%

Yields extraction and TW Clustering

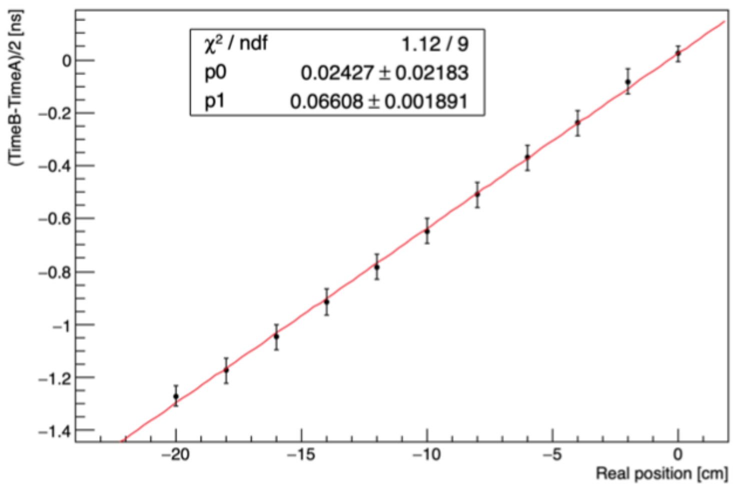
Same situation of above + problem of the ghosts→ to be managed with measurement of the position along the bar exploiting the time difference DeltaT at the edges of the bar



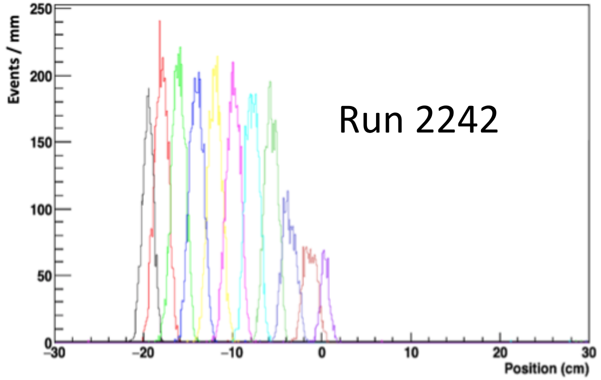
(N,M), (M,N), with N,M>1

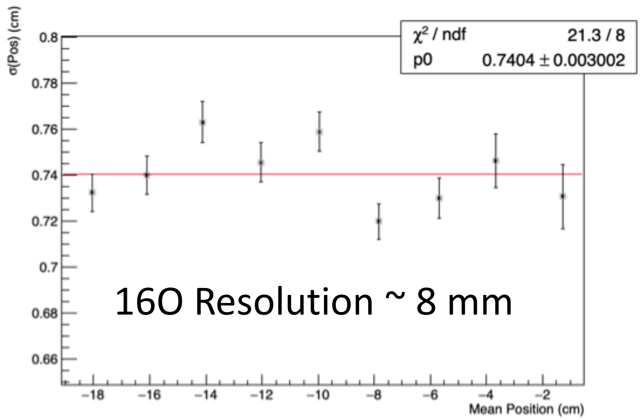
Yields extraction and TW Clustering

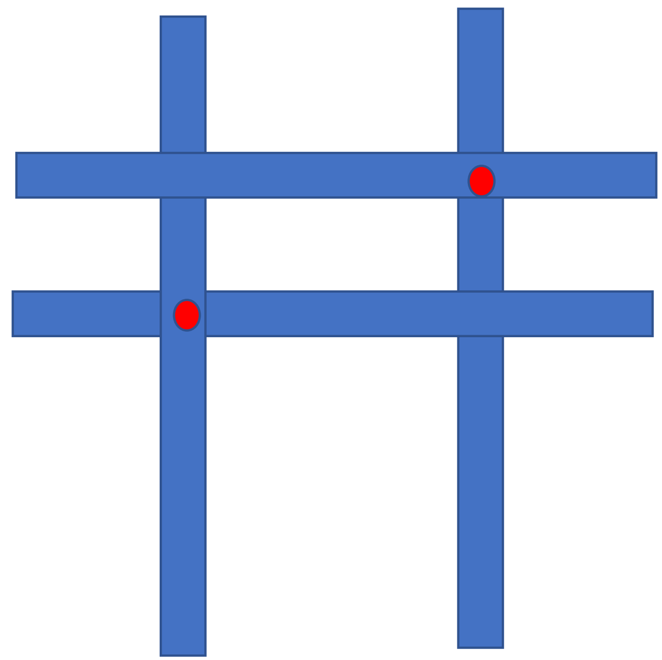
Same situation of above + problem of the ghosts→ to be managed with measurement of the position along the bar exploiting the time difference DeltaT at the edges of the bar



Light speed in the bars v:
1/v ~ 66 ps/cm







(N,M), (M,N), with N,M>1

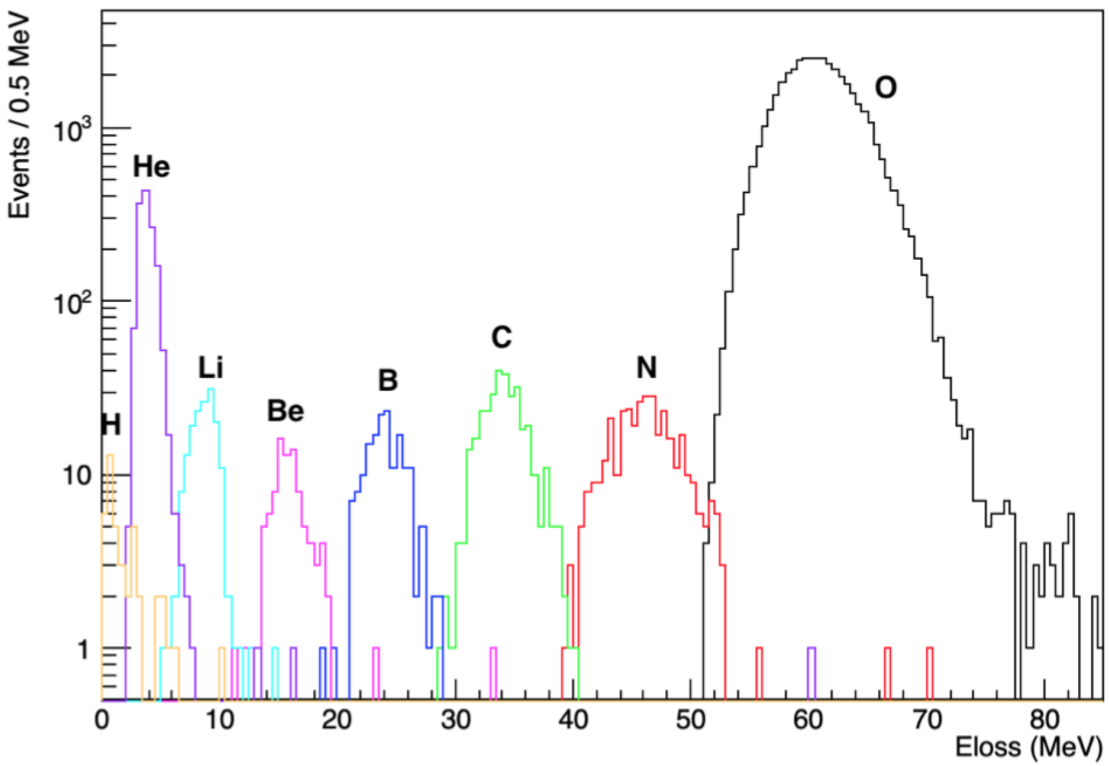
TW Clustering algorithm

- From these simple observations I follow the simple idea to train the TW cluster/point with the hits from the TW layer with higher occupancy to avoid to drop 25% of events due to pile-up
- When there is the same number of hits in the two layers the front hits train the clusters
- Noise can be further strongly reduced asking Zfront = Zrear (best choice in the end)

In SHOE: for each TWpoint the charge of the training hit and its MC track ID (useful for efficiencies evaluation) are assigned to the point

This fact, matched with the good position resolution from deltaT (better than bar crossing resolution), is a good reason in the future to keep as in GSI horizontal bars in the front layers and vertical in rear → actually this study should be repeated in presence of the magnetic field

Implementation of TW Clustering in SHOE

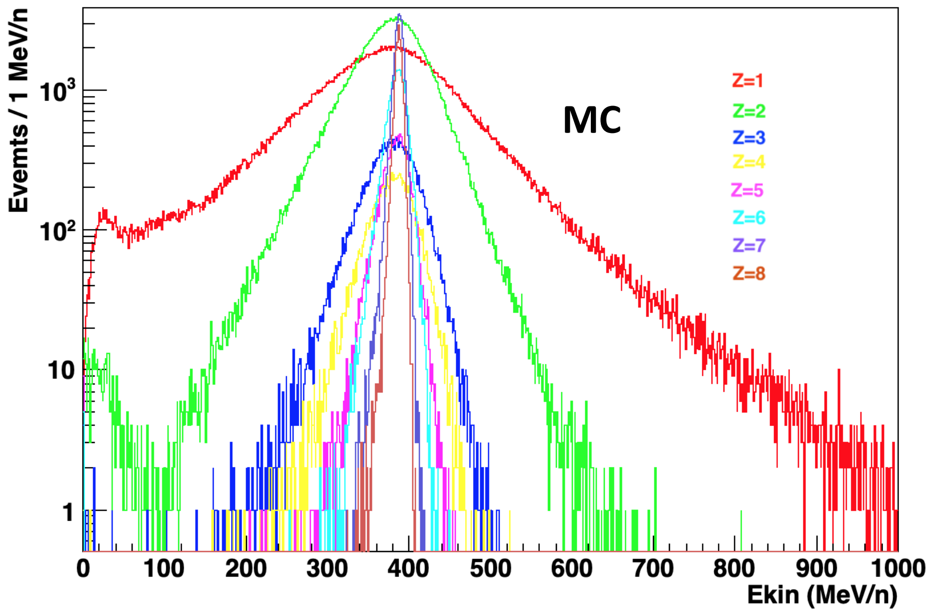


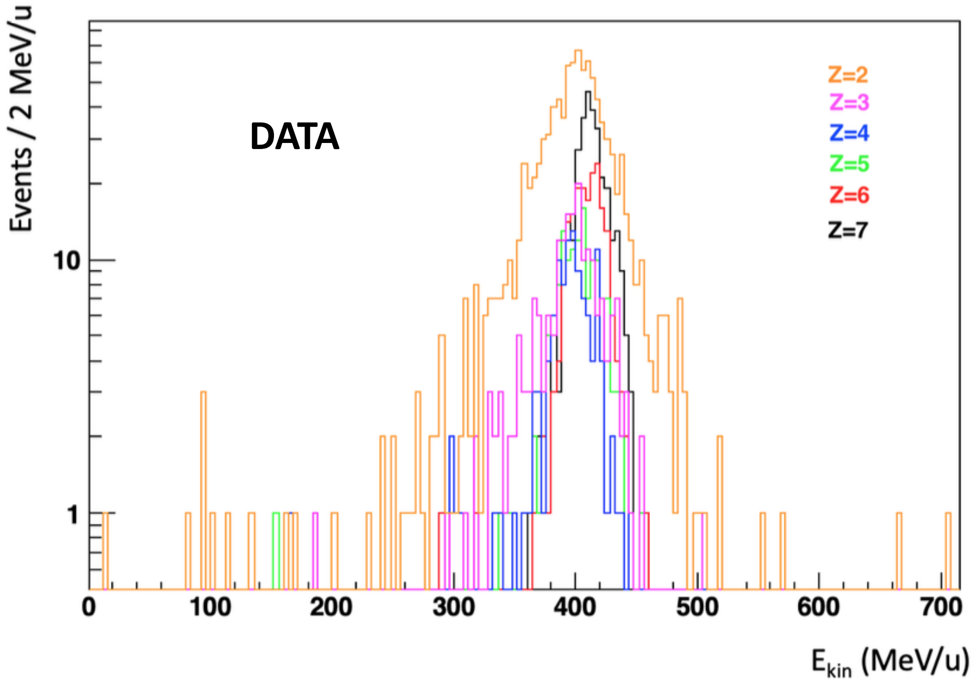
The combination of the Z identification and clustering algorithms implemented in SHOE provide a very good fragment charge identification on an event-by-event basis (DATA!!)

Provide the fragment yields for the measurement of the cross section

Efficiencies: denominator

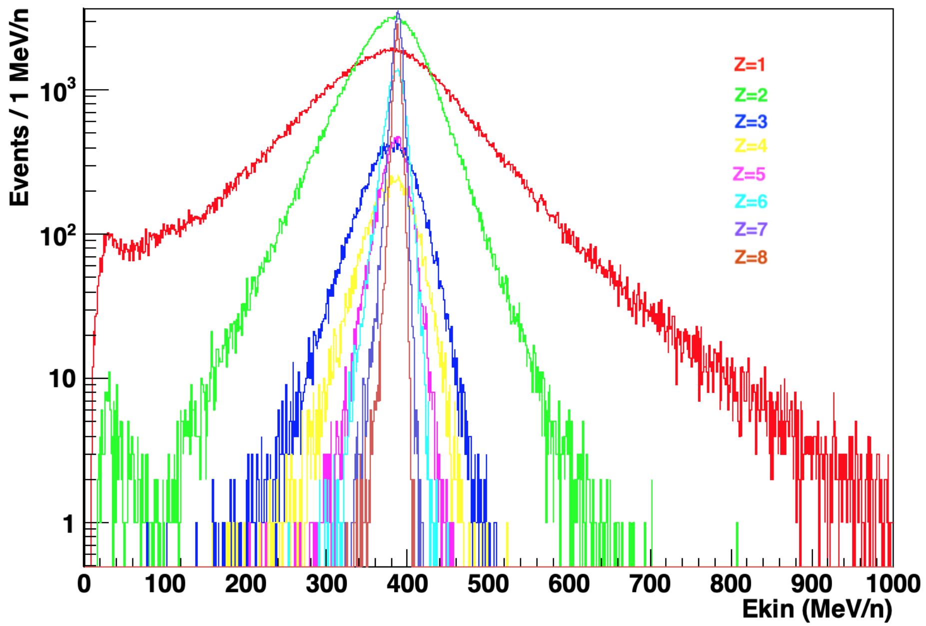
Production E_{kin} distribution of fragments out of TG





<u>Denominator</u>: Asking for only primary fragments with origin in Target produced on the TG in [-1,1] and escaping from it with θ<5.7° and an Ekin in the interval 100-600 MeV/n (from data distribution)

Efficiencies: numerator

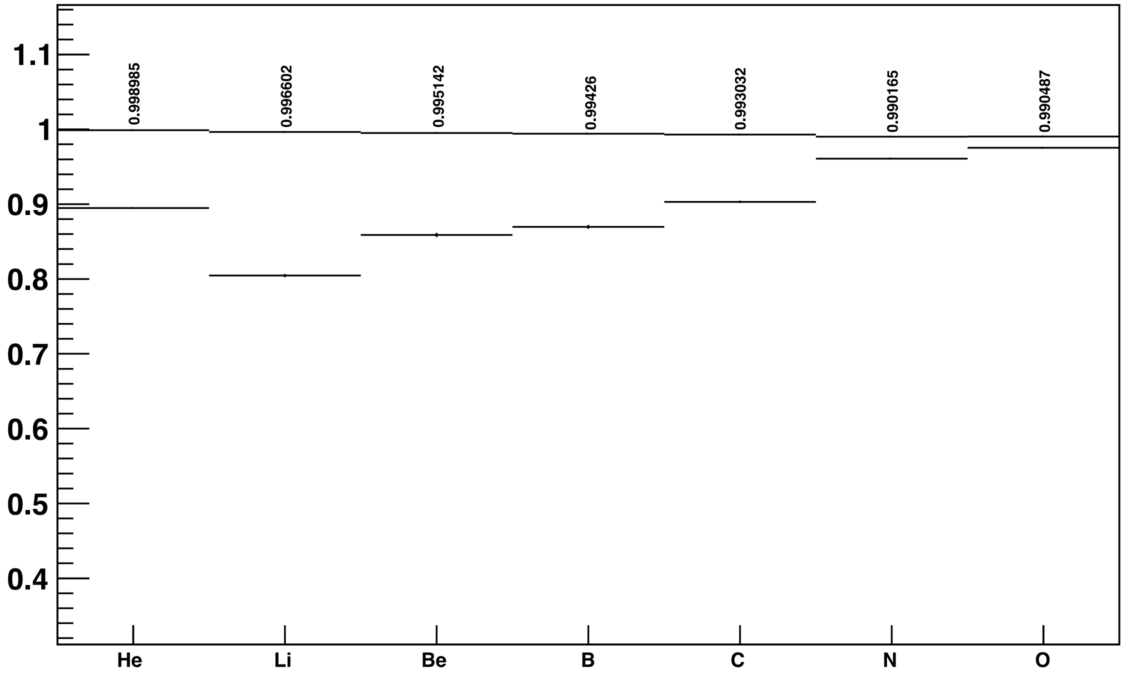


Numerator: Asking for a good TWpoint matched to primary fragments with origin in Target with production angle < 5.7° , beam projection on TG in [-0.7,0.7] and production Ekin in the range [200,600] MeV/n.

In reconstructed MC **Pile-Up is switched off and Z=Ztrue** (not reconstructed Z)

ON/OFF Request: Z_front = Z_rear

“Integral” efficiencies



Intrinsic efficiencies folded with TW clustering efficiency

Efficiencies in angle and “Ekin”